To Subscribers

THE CABINET CYCLOPÆDIA.

The Subscribers to this Work are informed that in consequence of the decease of the late Sir James Mackintosh, the Publication of the Third Volume of the "History of England," the greater part of which is printed, has been for a short time suspended. Arrangements, however, have been made for the completion of this Volume, and the continuance of the History; and the Editor hopes to be enabled to publish it on November 1st.

The Historical MSS. left by this distinguished person, including a large quantity in a state ready for publication, but referring to an epoch of the History subsequent to the reign of Elizabeth, have been purchased by the Proprietors of the "Cyclopædia," and placed in the hands of Dr. Lardner, with a view to the continuance of the "History of England." It is at present intended to continue the History to the date at which these MSS. commence, at which point they will be introduced.

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THE

CABINET CYCLOPÆDIA.

CONDUCTED BY THE

REV. DIONYSIUS LARDNER, LL.D. F.R.S. L.&E.

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EMINENT LITERARY AND SCIENTIFIC MEN.

Natural Philosophy.

CHEMISTRY.

BY

MICHAEL DONOVAN, ESQ. M.R.I.A.

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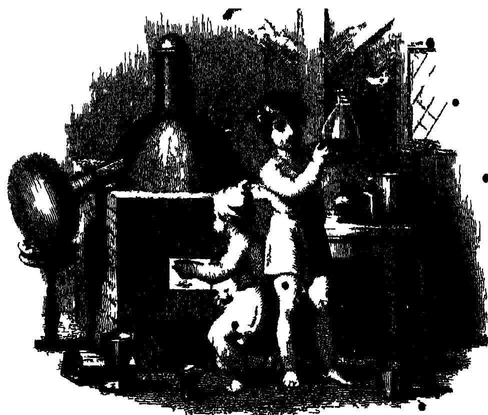
UPPER GOWER STREET

1832.

TREATI[illegible] ON [illegible]MI[illegible]

BY

[illegible]



ADVERTISEMENT.

The author of this treatise wishes it to be stated, that the following paragraphs in the original MS. have been expunged by the editor; and the paragraphs commencing with the words, "That water," &c. p. 66., and ending with the words "surrounding air, ascends," p. 67., have been substituted by him.

"Another fact of the same tendency is the following: — If two flasks — one containing water, and the other containing water holding some common salt dissolved — be both exposed to the air when it is below the freezing point, with a thermometer immersed in each, the temperature of both flasks will sink to 32°: the salt water will continue to sink until it is much below the freezing point of pure water, and, on account of the salt, it will not freeze: the pure water, as soon as it arrives at 32°, has a tendency to freeze; but it cannot do so without first parting with that caloric which is the cause of its fluidity. Accordingly, instead of cooling below 32°, as the salt water did, it remains steadily at 32°, and, at the same time, freezes; for the concealed heat, now extricated, has become sensible, and consequently keeps the ice at that temperature; although, but for this cause, the temperature must

have sunk in the same manner as that of the salt water did.

"That water does give out caloric in freezing, may be proved by another striking experiment. — Let two thin glass vessels be procured, equal in every respect: let a little pure water be poured into one, and over the water a little olive-oil; let an equal quantity of oil, without any water, be poured into the other; and let both glasses be exposed to the same temperature, below 32°. It will, in some time, be found that the water has frozen; that the oil above it is still liquid, although the oil in the glass which contains no water is frozen: and the reason is, because the water, in freezing, gave out so much heat as kept the oil liquid until that supply was dissipated."

CONTENTS.

PART I.

SURVEY OF CREATION.

CHAP. VI.

LIGHT.

CHAP. VII.

CONSTITUTION OF THE GLOBE.

SECT. I.

THE ATMOSPHERE.

SECT. II.

THE WATERS.

SECT. III.

EARTHS AND METALS.

SECT. IV.

ORGANISED STRUCTURES.

PART II.

ARRANGEMENT AND EXAMINATION OF THE MATERIALS OF CREATION.

CHAP. I.

ELEMENTS OR SIMPLE SUBSTANCES, AND THEIR IMMEDIATE COMPOUNDS.

CONTENTS.

SECT. VIII.

SULPHUR.

SECT. IX.

SELENIUM.

SECT. X.

PHOSPHORUS.

SECT. XI.

FLUORINE.

SECT. XII.

SILICON.

SECT. XIII.

BORON.

SECT. XIV.

METALS.

CHAP. II.

COMPOUNDS OF SOME ELEMENTS PRESENTED BY THE VEGETABLE KINGDOM.

SECT. I.

ACIDS OF VEGETABLES.

SECT. II.

ALKALIES OF VEGETABLES.

SECT. III.

OTHER PROXIMATE PRINCIPLES OF VEGETABLES.

CHAP. III.

COMPOUNDS OF SOME ELEMENTS AS PRESENTED BY THE ANIMAL KINGDOM.

CHAP. IV.

PART III.

PHENOMENA PRESENTED DURING SOME REMARKABLE CHEMICAL CHANGES.

CHAP. I.

OF SOME PROCESSES CONNECTED WITH ANIMAL LIFE.

SECT. I.

RESPIRATION.

SECT. II.

MAINTENANCE OF THE TEMPERATURE OF ANIMALS.

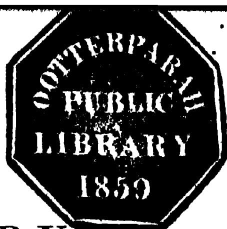
CHAP. II.

OF THE SPONTANEOUS DECOMPOSITION OF VEGETABLE AND ANIMAL MATTER.

CHAP. III.

OF COMBUSTION.

CHAP. IV.



ELEMENTS OF CHEMISTRY.

PART I.

CHAPTER I.

INTRODUCTION.

THE several divisions of science which treat of natural phenomena are so intimately connected, and have so many points of contact, that it is scarcely possible to explain the principles of any one, without assuming more or less of the results obtained in others. Chemistry stands peculiarly in this predicament. The properties of matter of which it more exclusively treats are closely connected with the mechanical theory of solids and fluids; and they are no less intimately related to those departments of physics in which the phenomena of heat, light, and electricity are developed and explained. In complete and independent treatises on Chemistry, it has therefore been usual to explain, in distinct chapters, so much of those parts of natural philosophy as is considered most necessary and useful to the researches of the chemical student. The present volume forming part of a series comprising distinct treatises upon those subjects, the introduction of any detailed discussion upon them is less necessary. It has been thought sufficient, in general, to refer the reader to the volumes of this Cyclopædia which are specially

devoted to these parts of science. Some brief explanation of the mechanical phenomena which will be principally alluded to, and which are most closely connected with chemistry, is, however, indispensable; and, in particular, a somewhat extended view of the phenomena depending upon heat has been considered advisable.

Matter, and all physical agents, are known to us only by their sensible effects; and when the notion of quantity is connected with them, that quantity must always be measured or estimated by some effect capable of being accurately appreciated by experiment or observation. The physical effects most intimately and universally connected with matter are *inertia* and *weight.* Inertia is the indisposition or inability of matter to put itself in motion, or in any way to modify or change any motion which it may have acquired from an external cause. In fact, it is that quality in which mere matter is distinguished from life. It is the absence of all ability for spontaneous change with respect to rest or motion. All experiment and observation prove that unorganised matter possesses this quality; and, therefore, that it will remain for ever at rest, unless it be put in motion by the application of some external cause; and, if once put in motion, will for ever continue to move, unless some external agency interferes to restore it to a state of rest.

It is proved by observation, also, that to put matter in motion requires the exertion of a certain force; and that to give the same motion to different masses of matter requires the exertion of different degrees of force. The *quantity of inertia* of a body is estimated by the *quantity of force* necessary to put it in motion at a given rate; and one body is said to have as much inertia as another, if the same impulse is capable of communicating to it the same velocity. One body is said to have twice or thrice the inertia of another, if it requires twice or thrice the force to cause it to move with the same speed.

The *quantity of matter* is a phrase of frequent occurrence in all parts of physics; and it is highly necessary that the student should have a distinct and well-defined notion of its meaning; the more especially as some confusion is frequently created by definitions of this phrase, founded on theory rather than on observation.

The *quantity of matter* of a body is, then, determined by its *quantity of inertia*; and two bodies are said to have equal quantities of matter, when they have equal inertia. If the quantity of matter in one body is said to be twice the quantity of matter in another, the meaning is, that one has twice the inertia of the other; or, that to give it the same motion will require twice the degree of impelling force.* The *mass of matter*, or the *mass of a body*, is also a term of frequent use. This word *mass* is to be understood as synonymous with *quantity*: the *mass* of a body is, therefore, the *quantity of matter* in the body.

If two masses of matter be placed at any distance from each other, and be uninfluenced by any external force, they will be observed to move towards each other, as if each possessed a certain virtue by which it is capable of drawing the other towards it. It is also found that, under the same circumstances, this effect increases as the masses or quantities of matter in the bodies increase. If the quantity of matter be double, the bodies will move towards each other with a double speed: if the quantity of matter be increased in a threefold proportion, the speed of their mutual approach will be also increased in a threefold proportion; and so on. It is likewise found, that the energy of this effect is increased in a certain proportion as the distance between the bodies is diminished; the more closely the bodies approach, the more rapid will be their motions: but this increase of rapidity is not in the proportion of the decrease of the distance, but in the proportion of the decrease of what arithmeticians call the *square* of the distance. This

* MECHANICS, Cab. Cycl. Chap. III.

attraction of bodies for one another is called GRAVITATION, OR GRAVITY. It is a universal property of matter; and is found to depend (other results being the same) on the *quantity* of matter alone, without any regard to the *nature* of the body. Thus, a mass of lead and a mass of iron, having equal quantities of matter,—that is, having equal inertia,—will exhibit this attraction in an equal degree. The results of astronomical observation prove that this quality belongs to all the great bodies of the universe; and all the facts upon which mechanical science is founded, prove that it is a quality found in all bodies composing the earth, and existing on its surface. The great mass of the earth itself has this quality in relation to all bodies in its neighbourhood. The moon and earth have a tendency to approach each other; and if the effects were not modified by other causes, they would actually approach and coalesce. Detached bodies on and near the surface of the earth are attracted by the earth. A body placed at any distance from the surface, and disengaged, will move straight towards the surface, and fall upon it. A body placed on the surface, will be pressed to the surface with a certain force. These are manifestations of the same principle; and the quality thus exhibited in bodies on and near the earth is called WEIGHT: weight is, therefore, a particular manifestation of the general principle of gravitation. From what has been just explained, it will be perceived that the weights of bodies are always in the same proportion as their quantities of matter.

The proofs that gravity is an universal property of matter are too numerous and complicated to admit of any development here. In fact, the whole science of ASTRONOMY may be regarded as one connected demonstration of the universality of this principle, so far as regards the great bodies of the universe; and the whole science of what is called TERRESTRIAL MECHANICS, a like demonstration of its universality, so far as regards our earth, and the bodies upon it.*

MECHANICS, Chaps. VI. and VII.

CHAP. II.

ATTRACTION OF GRAVITATION.

If a body be supposed to consist of particles of matter of equal weight, it follows that the greater the number of particles included within a certain volume or bulk, the greater will be the weight of the mass. If there be ten separate particles of matter, each gravitating with a force equal to 1, the gravitation of the whole ten particles, if united into one, would be equal to 10, and this would happen without reference to the bulk: the force of gravitation is, therefore, in proportion to the quantity of matter.

The quantity of matter constituting the bulk of any body is subject to much variation. If we assume any measure of bulk, and fill it up with leaden bullets, we have a certain volume or bulk of lead; if small shot be shaken in amongst the bullets, the *quantity* of lead is much increased, although the *bulk* remains the same: and even after this, a considerable quantity of smaller shot may be introduced without adding to the volume. Here then are three bulks, apparently the same, yet all differing in the quantity of matter which they contain, and, consequently, in their force of gravitation. A quart of ardent spirit mixed with a quart of water will make less than two quarts; as if the same penetration takes place between the particles of the two liquids that happens with large and small balls of lead. A mixture of a quart of oil of vitriol with a quart of water will bear the addition of a very large quantity of the solid substance called magnesia, before the total bulk of two quarts will be made up amongst them all, when cold.

The quantity of matter contained in any bulk is ascertained by the process of weighing. A cubic inch of pure solid copper will weigh $4\frac{7}{10}$ troy ounces; this,

accordingly, expresses its quantity. It is quite evident that another cubic inch of copper put into the opposite side of the balance will counterpoise the first; but it by no means follows that a cubic inch of any other metal will do the same. So much the contrary is the fact, that a cubic inch of standard gold * will exactly balance two cubic inches of copper; hence there is in the former, twice the quantity of matter that there is in the latter, the bulks being the same.

It appears, therefore, that equal bulks of different kinds of matter may have very different weights; and, in fact, every distinct species of body has a weight in a given bulk peculiar to itself. This property is hence called the specific gravity, or density of bodies; and it is of great value in distinguishing one kind of matter from another, it being different in almost every kind. To ascertain the specific gravity of bodies, therefore, the bulk and weight are to be taken into account. If a cubic inch of copper weighs 4·7 troy ounces, no more is learned from this than its absolute weight; but if a cubic inch of standard gold weighs 9·4 troy ounces, not only is its absolute weight known, but it becomes manifest that this metal is twice as heavy as copper; or, in other words, contains twice as much matter, bulk for bulk. In the same manner might be tried the weights of cubes of all other metals and solids, and it would thus be found how much heavier or lighter they are than the cube of copper: this would give their specific gravity, or their relative weight compared to copper; but there would be many sources of difficulty and error in such a method. First, it would be almost impossible to procure true cubes or other figures; they would not be all of precisely the same size, and the specific weights would be all referable to copper. On these accounts another method is adopted. As different specimens of copper may be more or less heavy, according as they are more or less pure or hard, it is necessary to seek a substance

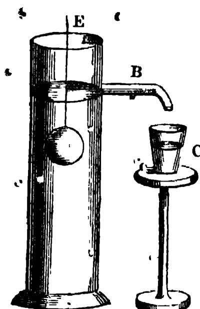
* Made standard by one twelfth silver.

not liable to variation: such is water; any determinate bulk of which, when pure and at the same temperature, is always the same in point of weight, and hence it is preferred as a standard of comparison. Thus, instead of saying that the specific gravity of standard gold is twice that of copper, we ascertain how many times the gold cube is heavier than the same measure of water. This is easily done; for if a solid be immersed in a vessel of water, the water will rise in the vessel, and fill an additional space equal to the bulk of the solid. The water that is thus displaced, having weight, has a tendency to fall back, and in its turn to displace the solid immersed; the water, therefore, presses on the solid, and tends to push it upwards, although it may not succeed so as to occupy its place. Now, it is proved in hydrostatics *, that the force with which the solid is pressed upwards must be precisely the weight of the quantity of water displaced by the solid; that is, its own bulk of water. Hence we derive this conclusion,—that when a solid is immersed in a fluid, the solid is pressed upwards by the weight of as much of the fluid as is equal to the bulk of the solid; the solid thus pressed upwards must, therefore, be so far buoyed up by the fluid, or, in other words, must lose that much of its weight by the immersion. That the apparent weight is diminished by immersion in water, is easily proved. Thus, let a person raise the heaviest stone that his strength permits him from the bottom of a river; while the stone is still under water he can lift it, but let him attempt to raise it entirely out of the water, and all his efforts will prove ineffectual. In the same manner, an angler, with a single hair and slender rod, draws a fish with ease through the water; but he may snap the hair or rod in two, if he should attempt to raise the fish altogether out of the water.

It is easy to prove, by experiment, that when a solid is immersed in water, it, for the time, apparently loses

* For a detailed account of this and other matters alluded to in this chapter, see the Treatise on HYDROSTATICS, Cab. Cycl.

as much of its weight as the bulk of water displaced by it weighs; and that, consequently, it acquires buoyancy, or an upward pressure, equal to the weight of the displaced water. Let a vessel, suppose of glass, A, fur-



nished with a lateral pipe B, be filled with distilled water, until some has run out at B, and it has ceased to drop. Then place under it the empty receiver C, and suspend in the water a hollow glass ball, fastened by a thread E, to one of the pans of a pair of scales, and previously counterpoised in the air. On immersion, the balance will immediately be subverted; the glass ball, according to the portion immersed, will displace water, and that water will run into the receiver C. When the water has totally ceased to drop from the pipe B, pour the whole quantity contained in C into the pan of the scale from which the glass ball is suspended, and it will be found to restore the balance. This proves, that the weight of water displaced by the glass ball was precisely the weight which the glass ball lost by immersion; or, in other words, acquired in buoyancy: and it is obvious that the bulk of the water displaced could not be otherwise than equal to the bulk of the glass ball. If the water displaced by the ball, and the ball itself, be equal in weight, then the ball and the water are of the same specific gravity, and the ball will float in any part of

the water without any tendency to rise or fall. If the weight of the water displaced be greater than that of the ball, the latter will be pressed up to the surface, where it will float, and a part will remain above the surface. If the weight of the water displaced be less than that of the ball, the latter will fall, by its difference of weight, to the bottom, and remain there.*

The law being now understood, that when a solid is immersed in a fluid, the solid loses as much of its weight as its own bulk of the fluid weighs, we are presented with a method of ascertaining with precision the weight of the quantity of water that is equal to the bulk of any solid. We have no more to do than to weigh the solid in a delicate balance or scales; then to tie it with a horse-hair to a hook in one of the pans, and let it hang in pure water so as to be immersed: it will be found to be buoyed up more or less: then to add weights to the lighter dish of the balance until the equilibrium is restored; the weights so added will be the weight of the water which equals the solid in bulk, and was displaced by it. Suppose that when the solid was weighed in the air, its weight was 6 ounces, and that when weighed in water it lost so much that 1 ounce was required on that side of the scale to restore the balance; then 1 ounce was the weight of the solid's bulk of water, and the solid weighed six times the weight of its own bulk of water. Hence we say that the specific gravity of that solid is 6: and we mean that it is six times heavier than an equal bulk of water. In all such cases the weight of the displaced water is called unity, or 1: but as fractions often occur, one is considered 1000, and then the above specific gravity must be written 6000.

The very same consequences result, and the same explanations apply, be the medium, in which the bodies are immersed, what it may; whether it be water or any other liquor, or air or any other gas.

In the common process of weighing, the bodies are immersed in a medium, different, it is true, from water.

* HYDROSTATICS, Cab. Cycl. Chaps. V. and VII.

but still sufficient slightly to influence the results. When an ounce of glass and an ounce of lead hang from a scale-beam in the air, they counterpoise each other, although they are, in point of fact, somewhat different in weight: for, being unequal in bulk, they displace unequal bulks, and therefore weights, of air; and these unequal weights of air press upwards differently on the glass and lead, and the difference must be compensated by a corresponding, although trivial, difference of weight between the glass and the lead, if they are to remain in a state of equipoise.

That the air does exert this unequal pressure on the two bodies of different bulks, can readily be proved by making the experiment on two bodies in which the difference of bulk is considerable, weighing them first in air so as to balance, and removing the air by the air-pump, when the balance will be immediately subverted.

It therefore appears, that, in order rigidly to ascertain the relative weights of any two bodies, when the specific gravities are very different, they must be weighed in a vacuum, as it is only in this way that the influence of bulk is obviated. But if the specific gravities be the same, they may be weighed indifferently in a vacuum, or in air, or in any liquid. However, the inaccuracy in weighing any body in the air, unless it be exceedingly voluminous compared with the body against which it is weighed, is so trivial, that it may be disregarded: and when any substance is said to weigh an ounce, it is understood to do so in air.

There are circumstances to be attended to, with regard to temperature, which will be explained more fully hereafter. For the present it is enough to say, that, in all comparisons of specific gravities, the temperature of the solids or liquids under examination must be the same; for difference of temperature creates difference of bulk: cold contracts, and heat expands, all bodies. When no temperature is expressed in stating the specific gravity of any body, that of 60 degrees of Fahrenheit's thermometer is to be understood.

CHAP. III.

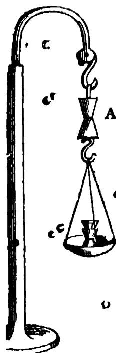
ATTRACTION OF COHESION.

Having adverted in a general way to the attractive power which the bodies of the universe exert upon each other; and having stated that this agency is exerted by the globe of the earth as well as by the smallest masses composing it, and that it gives origin to great varieties in the constitution of matter, it remains to enquire how far the minute particles of which these masses consist are affected by any attractive influence.

If we examine the materials of the globe, we perceive that some are hard and dense; that others are soft and porous, that water is destitute of solidity; and that the atmosphere is far more attenuated. If a certain force be applied to a piece of glass, it is resisted; but if the force be increased, the glass is broken, and by repetition of the process may be reduced to powder. The glass is now separated into the parts which previously offered resistance to the change, and which, consequently, were held together by some force. This force, therefore, is the cause of the solidity of the glass: it was obviously an *attraction* of the parts to each other that caused them to cohere; and hence it is called the attraction of *cohesion*. It is also called the attraction of *aggregation*, because it aggregates or assembles and retains the particles of bodies in the state of a solid.

The evidence of the existence of cohesion is not merely inferential from the constitution of solids, but can be proved to act between separate atoms and masses of matter. A mass of gold can be beaten out into a thin film, which could not happen if its constituent particles did not glide over each other and join new ones during the hammering; yet still they are found to cohere. Two distinct masses of matter may be made to cohere by con-

tact. Thus, let two pieces of lead be formed in such a way that two of their surfaces may be readily cut fair with a sharp knife, and that when the cut surfaces are applied to each other as at A, they will both hang in the same perpendicular direction. Let a scale-pan be attached to one, and let the other be suspended from a standard. If the two surfaces of lead be forcibly pressed together with rather a sliding motion one over the other, and the compound piece then hung up, they will cohere with so much force that weights to the amount of several pounds may be gradually put into the scale-pan before they separate.



I made the experiment with plates of lead one eighth of an inch thick; the surfaces in contact were each five sixths of an inch long; perhaps the real physical contact was not more than one third of this, yet they sustained a weight of three pounds. It might be, and indeed was once, supposed that the air having been excluded by the close contact of the contiguous surfaces of lead, there was a certain degree of atmospheric pressure tending to keep them together; but this was disproved by Morveau, who showed that the surfaces cohered just as forcibly when the whole apparatus was put under the receiver of an air-pump, and the air withdrawn.

With regard to this kind of attraction, called cohesion, we have to consider it under two conditions—1st, when its operation is suspended, and, 2d, when it is restored.

Common experience is sufficient to prove that the force of cohesion is very different in different bodies; some will scarcely permit the separation of their parts by almost any ordinary force; while others, with difficulty, retain the solid form. When a solid is broken down by mechanical means, its cohesive force has been overcome; the operation of this force is suspended; and the body is now said to be mechanically divided. How-

ever fine this powder may be, a microscope will prove that it is composed of grains, every one of which is a solid of the same nature as the original; and there is a limit which, in the process of pulverisation, cannot be surpassed.

Although these particles are the smallest that can be procured by mechanical division, they are by no means the smallest that can be obtained by other means. Let, for instance, a piece of sugar be reduced to the finest powder; its parts are still discoverable to the eye; but let water be thrown on it, and it presently disappears altogether; not a particle can be perceived by the most powerful magnifiers: it is now reduced to its smallest parts; yet they are not destroyed, for they may be recovered.

In declaring that these are the *smallest* parts, a question is taken for granted, on which philosophers are by no means agreed, namely, whether there is any limit to the smallness of the particles to which solids can be reduced; or, in other words, whether or not matter is infinitely divisible.* It will be shown hereafter, that, unless we admit the finite divisibility of matter, and the existence of atoms or molecules, the most important series of phenomena in the science of chemistry will be left in the situation of ultimate facts which, on the other hand, are beautifully and completely accounted for by the atomic hypothesis. The happy explanation which this series of phenomena receives from the admission of limited divisibility, is a strong argument in favour of the truth of that doctrine.

Whatever may be the truth on this subject, it is certain that the practical divisibility of matter is truly astonishing. Silk, as spun by the silk-worm, is so fine, that twelve grains' weight measure one mile.† Gold can be beaten out into continuous leaves so thin, that, according to Boyle, 50 square inches will weigh but 1¼ grain; ac-

* See MECHANICS, Cab. Cycl. Chap. II.
† Shaw's Boyle, i. 404.

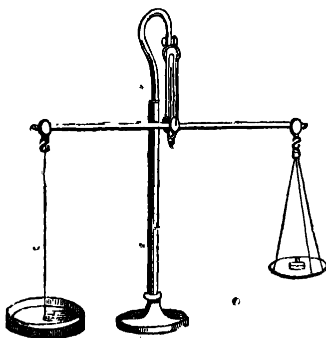
cording to others, 56 square inches will weigh but a grain. The gilding on silver wire is much thinner; Dr. Halley showed that it may be but $\frac{1}{134500}$th part of an inch. Boyle proves that an ounce of gold can be thus extended on silver to the length of 155 miles; others say 1300 miles; and others, again, have calculated that 14,000,000 of films, such as exists on the wire, would be required to make up the thickness of an inch, although an equal number of leaves of common printing paper would be nearly three quarters of a mile in thickness. Dr. Wollaston made a gold wire so thin that an ounce of it would extend 50 miles. The hundred thousandth part of a grain of gold is visible to the naked eye. If five avoirdupois pounds of pure water be poured into a glass globe which it fills, and one grain weight of *aloetic acid* (a substance obtained by the action of nitric acid on aloes) be added, the whole will, after some time, assume a fine crimson colour; which could not happen unless the grain of aloetic acid had been divided and equally diffused throughout the whole volume of water. It is possible to see so small a quantity of water as a thousandth of a grain, and this portion of the solution must contain a thirty-five millionth part of a grain of aloetic acid. We have, therefore, actually divided a single grain of this substance into 35,000,000 of parts, and we know that the division can be carried much farther The substance called *cerulin*, obtained from indigo, dissolved in the same proportion in water, gives it a blue tinge throughout.

Not only are the constituent particles of different kinds of matter held together by a different degree of cohesive force, but we can lessen or increase this force by artificial means. It is not possible, however, to destroy it: so far as human means are concerned, it seems as indestructible as matter itself: all that we can do is to suspend its operation; and then it is always ready to resume its energy when circumstances permit. All terrestrial bodies are found in one or other of the three

following states,—the solid, the liquid*, or the state of air or vapour. Between solidity and liquidity there are degrees: a body may be more or less solid; it may be so soft as to be almost a liquid: but airs or vapours always maintain the most perfect fluidity; they never approach the other two states, and they remain like the atmosphere around us. There are many bodies which may be made to exist in any of these three states; and, in the spirit of generalisation, it has been even supposed that this is true with regard to all matter, although facts are not yet abundant enough to warrant us in considering such an assumption as established. Ice is solidified water; when heated it melts into the state of a liquid; and this liquid, by being further heated, evaporates into the state of air or vapour called steam. This part of the subject will be resumed in its proper place: it has been introduced here merely for the purpose of observing, that although, when a solid becomes liquid, its cohesion is said to be suspended, yet it is only its cohesion as a solid that is suspended, and we are by no means to suppose that the fluid produced is destitute of all cohesive force. On the contrary, the cohesion of liquids is an appreciable force, and exerts an agency easily rendered manifest. Thus, if a particle of quicksilver, which is a metal in a liquid state, be brought as near another particle as is possible without their touching, they both preserve the globular form, which they naturally assume in consequence of the mutual attraction of their parts, acting in the same way as gravity does, in producing the sphericity of the celestial bodies. If they be brought so near as barely to touch, they instantly coalesce, their separate outlines are lost, and they form one larger globule; or, in other words, the attraction of cohesion draws the particles of both globules, hitherto separate, into close contact, and holds them united. But so

* The word *fluid* is used by chemists in rather a loose sense: it is merely opposed to a solid, and means either a liquid or a gas. In physics, the word is a genus of which the species are gas and liquid, otherwise expressed by elastic and inelastic fluids; and, in strictness, it is improper to confound one with the other.

small is the distance to which they must be approached before they unite, that the finest dust on their surface prevents the union. Another case of the cohesion of liquids is witnessed when we immerse a glass rod in water, and draw it out, holding it perpendicularly; the water forms a pendulous drop, and remains suspended. Here the attraction between the glass and the water sustains that portion of the drop next the glass; but the lower portions of the drop are prevented from falling off by their own cohesion. It is the same cohesive power that preserves small portions of quicksilver in the globular form; or drops of water on dusty surfaces; or drops of oil on wet surfaces: otherwise, they would all lie flat, like films, according to the laws of gravity. The cohesion of a liquid can be strikingly



shown by an easily executed experiment. Let one of the scale-pans of a balance be removed, and a disc of tin-plate be hung by a thread in its place. Let the disc of tin hang horizontally in a shallow vessel, but not touching the bottom, and let the balance be brought to an equipoise. If water be poured into the vessel as high as the tin disc stands in it the two surfaces will adhere, and with such force that weights proportionate to the surface engaged may be put into the opposite side with-

out forcing them asunder." When the weight in the opposite side is sufficient, it will even be seen, if the vessel be of glass, that the water is raised under the disc, above the level of the surrounding water, so great is the force that opposes the separation of the stratum of water which adheres to the disc. This experiment furnishes an instance of the cohesion of a solid to a liquid, and of the particles of a liquid to each other. By the same apparatus we can prove that different liquids have different degrees of cohesion: for while the weights are in the scale-pan, and the water is thus raised above the level, if a little ether be poured into the vessel, it floats on the water, takes its place, and instantly the tin disc is detached.

Airs and vapours exhibit no cohesion: they are influenced by an opposite force, which will be treated of hereafter. It now remains to consider the restoration of cohesion to bodies in which this force had been suspended.

The simplest case of this kind is the following. If a piece of lead, or any other metal, be melted in the fire, its cohesion is suspended; it becomes a liquid: but if it be allowed to cool, its cohesion again begins to act, the particles attract each other strongly, and it soon becomes as solid as ever. Here is a plain case of the suspension and restoration of the cohesive attraction, from a cause that will be enlarged on hereafter.

The same may be effected through the intervention of a liquid. If a large quantity of sugar be dissolved in a small quantity of boiling water, and the syrup allowed to grow cold, the attraction of cohesion will begin to take effect between its particles, and at length the sugar will once more become a solid. But, in this case, as in many others, it is worthy of attention, that, whatever be the original state of the sugar, it always, in resuming its solidity, assumes a particular form — one of great regularity and beauty. It was originally opaque; it is now transparent: it was originally a shapeless mass; it is now a prism of sixs ides, in regularity and

lustre scarcely to be surpassed by the products of the lapidary's wheel. A solid of this symmetrical form, and of spontaneous production, is called a *crystal;* and the process by which it is produced is called *crystallisation.*

There are numberless other substances which are capable of assuming the crystalline structure, of one shape or other: common sea-salt, alum, and saltpetre, are instances familiar to every one. Many bodies are found naturally in the crystalline state, as various precious stones and minerals.

With regard to artificial crystals, there are two modes of producing them: either by dissolving the substance of which they are to be composed in as little boiling water as will suffice, and allowing the *solution* (as the dissolved substance is called) to cool; or by melting the body by fire, without water, and allowing it to cool quietly and slowly. In the instance of certain substances, when a part has solidified, the liquid part is to be poured off, and the residue will have the crystalline form. It does not, however, follow that, in crystallisation, the same body invariably assumes the same form: the fact is otherwise; there may be several forms of crystals belonging to one body, but in one or other of these it is sure to crystallise, and not according to any other model. It is also true that very different kinds of matter may crystallise after the same model.

Bodies, whether solid, liquid, or vaporous, are capable of assuming the form of a crystal. If sulphur be melted into a liquid, it will, on cooling, crystallise: if water be cooled to a low degree, it will shoot into crystals, and form ice; and various vapours, such as that into which camphor is converted by heat, will, when cold, change into crystals. There are several metals which, when slowly cooled after being melted, will crystallise.

The facility with which bodies assume the crystalline form is very various; some doing so with great ease, and others with great difficulty. The general method of obtaining crystals from substances which dissolve in water is to add the substance to the water at a boiling

heat, and in as great a quantity as the water is capable of holding in solution. As the liquor cools, the crystals are produced; and the more slowly it cools, the more regular the crystals. Sometimes it will be necessary to reduce the liquor to the freezing point before it will crystallise; and sometimes it will show no more tendency to do so when cold than when hot; in which case the water should be gradually boiled away until the crystals have formed abundantly: it is in this way that common sea-salt is crystallised. Motion promotes crystallisation; but rest promotes regularity of the shape of the crystals.

The tendency to crystallise is often so nicely balanced by the force which resists it, and which will hereafter be treated of, that inconsiderable causes operate for or against the change. If a quantity of hot water be made to dissolve as much Glauber's salt as it can, and if the solution, still hot, be poured into a glass globe, which it just fills, and the mouth of the globe tied over firmly with moistened double bladder, it will not crystallise even when cold, provided no agitation has been used. Merely opening the covering of bladder, or throwing in a small crystal of the same salt, or touching the surface of the liquid with a metallic point, will instantly cause a crystallisation to commence, which will immediately extend downwards, in a singular manner, through the whole globe, and the contents, instead of being fluid, will become solid. So trifling are the causes which effect this so long suspended crystallisation, that the nature of the phenomenon has never been understood, notwithstanding that much investigation has been expended on it. It is a singular fact, that, in the crystallisation of this salt, and a few others, light has been observed to be emitted when the experiment is conducted in a dark room. Melted phosphorus often comports itself in the same way with regard to suspended solidification; and there are other similar instances known.

From all that has been said, it appears that matter is susceptible of being divided into particles so minute as

to surpass all comprehension; that this division is in all probability not without a limit; that these minute particles are held together in the solid state by a powerful force or attraction, called the attraction of cohesion or aggregation; that this force is manifested more strongly in solids than in liquids, although in the latter it is still discoverable; and, lastly, that in some conditions of matter, although it exists, its operation is suspended, but it is ready to come into action as soon as circumstances permit.

CHAP. IV.

ATTRACTION OF AFFINITY.

THE natural forces, gravitation and cohesion, noticed in the former chapters, belong, in their full development, more to mechanics than to chemistry. Hence, although some preliminary pages have been devoted to these subjects, we have abstained from enlarging on them. There are, however, other forces in nature to be considered, which fall more exclusively within our province; and which, so far as this planet is concerned, act a part equal in importance and interest to any other.

If a rod of iron be immersed in a vessel of water, on drawing it out it is found that some water has adhered to it; but if a rod of iron be immersed in a quantity of mercury, on being withdrawn no mercury adheres. Both of these facts are easily recognised as dependent on the effects of cohesion. The attraction of cohesion took place between the particles of the iron and those of the water; the same attraction, it is true, subsisted between the particles of water which were drawn out of the vessel and those that remained in it, but the attraction between the iron and water predominated. Not so when the iron

was dipped in mercury; although there was an effort at the exertion of the cohesive attraction, it was not efficacious, because the cohesive force keeping the particles of mercury together was superior. But if a rod of bright gold be immersed in mercury and taken out, it will be found that the gold has drawn up a coating of mercury which cannot be wiped off; the gold is rendered white; and, if left long enough in the mercury, it becomes soft.

In this case the mercury adhered to the gold rod, and was drawn up with it, in opposition to the laws of gravitation, and to the cohesive force existing between the mercurial particles. The question occurs, Was the mercury drawn up by a cohesion acting between it and the gold? But it is answered in the negative by the fact, that the mercury cannot be wiped from the gold, nor removed by any degree of mechanical force: for if the surface be scraped until the whiteness be removed, a separation is not effected; the scrapings contain both gold and mercury.

Now, since the influence which caused the mercury to be drawn up by the gold was evidently some sort of an attractive force, and since it was not the attraction of gravitation or of cohesion, it must be some other, — something unlike either of the forces which we have been considering. Accordingly, it is to be acknowledged as a different exhibition of the attractive force that pervades all matter; it is distinguished by the name of *chemical attraction*, or simply by the term *affinity*, — a more convenient but less expressive term; and it differs from all known forces in its agency.

If a piece of lead be melted, and a bit of block tin be laid gently on its surface, it floats there in the same manner as a cork would on water; because tin is specifically lighter than lead. In a short time the tin will melt with the heat; and being specifically lighter, we should expect it not only still to float, but to constitute the upper stratum when the two metals have grown solid by cooling. It happens, however, otherwise: for we find

neither the lead nor the tin in their respective situations; both metals are perfectly blended; and a particle cut from the lump, whether top or bottom, will be found composed of both tin and lead. Now, it is to be enquired, Why was the greater weight of the lead overcome, so that it was drawn upwards through the tin, and mixed with it at the surface? and why was the greater lightness of the tin overcome, so that it was drawn down through the heavier lead to the bottom? Here, again, we find an attractive force acting in opposition to gravity; and it is another case of the same attraction or affinity which caused the gold to join the mercury. We see, also, that this affinity does not always subsist between bodies, at least in effective strength; for the affinity of the iron rod to mercury was found incapable of overcoming the cohesion of the mercury.

This kind of attraction acts upon matter in all states, whether solid, liquid, or gaseous. Every one knows that sugar is heavier than water; accordingly, when a piece of sugar is thrown into a vessel filled with water, it instantly sinks to the bottom: yet, after a time, the sugar is no longer to be found where it was deposited; but by the taste of the water it will be proved, contrarily to the laws of gravity, to have ascended towards the top. To the top, and all other parts, it must, therefore, have been gradually attracted; and the same would happen with salt, and various other articles, between which and water affinity is known to subsist. But if, instead of sugar, we throw a stone into water, it would remain there for ever undissolved, because its attraction to water is not sufficiently great.

The same would happen with two fluids between which affinity subsists: thus, spirit of wine is lighter than water; and if it be poured cautiously over water, it will float; but after a length of time it will be found to have descended to the bottom, and to be equally diffused through all parts, in consequence of the affinity exerted by the water to it. If, on the other hand, oil be poured on water, it will remain there during any

period; for it is lighter than water, and is not attracted by any strong affinity to that liquid.

A familiar instance of the attraction of an air or gas may be found in the air which is expired from the lungs, and which is different from atmospheric air before it enters the lungs. If we breathe for a few minutes upon a small quantity of slaked lime mixed with a little water, the lime will attract some of the air breathed on it, and will detain it. To prove that it does so, we have only to pour on a little strong vinegar, which will cause all the air that had been attracted to bubble off visibly. But atmospheric air, were it perfectly pure, which it never is, might for ever remain in contact with lime without being absorbed, because no effective affinity subsists between them.

This attraction does not act at any distance that can be perceived; its existence is only discoverable by its effects: but its consequences are very striking, and the changes it produces are of such a nature as cannot be overlooked. In the case of the cohesion of two masses of matter — suppose two pieces of lead, glass, or any other substance — they merely stick together with more or less force; the matter is in no respect altered. A piece of tin and a piece of copper may be made so smooth as to permit their being brought sufficiently near each other to allow the attraction of cohesion to operate; they then cohere together with some force, yet the two metals remain in every respect unchanged in their nature. But if their chemical attraction be allowed to operate, as by melting them, the masses of each metal do not merely remain in juxtaposition, as in the former instance; a mutual penetration of substance seems to take place; the particles run together and mix, so that no part of the resulting mass possesses the properties of either tin or copper. In this case of attraction, the only view which can be taken of the change produced is, that the ultimate particles, or most minute portions of which the mass of each metal is composed,

attract each other and unite, particle to particle: this is expressed in chemical language by saying that the two metals *combine.*

By thus melting the two metals into a *combination,* extraordinary changes are produced. Thus, copper is of a reddish-brown colour, and tin is white; we should expect the mixture of both metals to be a mixture of both colours, that is, a paler reddish-brown; but the real colour of the mixture is gray. Again, copper is a soft metal; tin is still softer; but the mixture is exceedingly hard. Copper is also a light metal; tin still more so: but the mixture is much heavier, bulk for bulk, than either. Of this, Glauber, one of the earlier chemists, gives a plain illustration. He says, "Make two balls of copper, and two of pure tin, of one and the same form and quantity, the weight of which balls observe exactly; which done, again melt the balls into one, and presently pour out the mixture melted into the mould of the first balls, and there will not come forth four, nor scarcely three balls, the weight of the four balls being reserved." It appears, then, that the same weight is condensed into a smaller bulk. Another, and not the least remarkable change, effected by the combining of the two metals, is on their sound. If three bells be cast from the same mould; one of copper nearly pure *, one of good tin, and one of a mixture of both; the copper bell will have a dull, heavy sound; the tin bell almost no sound; but the mixture of both will have a sweet, clear, and musical sound. Hence bell-metal is composed of a mixture of tin and copper.

What the nature of the change may be that is thus produced on the two metals, cannot be explained; but it is certain that, in the mixed mass, the contiguity of a particle of one kind of metal produces a very decided change on the properties of the adjoining particle of the other; and a property is produced by their union, which neither particle apparently possesses.

When I say that a particle of one kind of metal acts

* It could not be cast if the copper were perfectly pure.

on the contiguous particle of another, it is necessary to explain what is meant by contiguity. It is not meant that the particles should be merely very near each other; they must be in actual contact — at least, in contact so far as is compatible with the constitution of matter, as will be hereafter explained.

Were this contact not an indispensable condition for the production of the change of properties occasioned in the tin and copper by their mixture, it might be supposed that the same would occur on mixing extremely fine filings of copper and tin; but this would not be realised in point of fact. By no mechanical means in our power is it possible to bring the particles of the two metals into the close degree of contact required for the complete change of properties which the bodies concerned are capable of, and which is effected so easily by melting them together. By melting, the metals naturally fall down into what are called their ultimate or most minute constituent particles, and no mechanical means are competent to this effect.

The change of properties which takes place when chemical attraction acts, is not confined to metals, but is a general result in every case where different bodies are brought into this state of combination or chemical union. Frequently we find that the properties of each body are totally changed; and that substances, from being energetic and violent in their nature, become inert and harmless, and *vice versâ*. For instance, that useful and agreeable substance, culinary salt, which is not only harmless, but wholesome, and absolutely necessary to the well-being of man, is composed of two formidable ingredients, either of which taken into the stomach proves fatal to life; one of these is a metal, and the other an air; the former is called *sodium*, the latter *chlorine*. When presented to each other, the violence of their nature is manifested by their immediately bursting out into flame, and instantly they are both deprived of their virulence. Can any thing be more striking than the change of properties in this case; and who could have

supposed that culinary salt is composed of a metal united to an air? The medicine called Glauber's salt is another instance: it is composed of two caustic poisons of different kinds; one called oil of vitriol, and the other barilla or soda. There are also two substances known to chemists, which are disgustingly bitter liquids; one is called nitrate of silver, and the other hyposulphate of soda; when mixed, they form a compound of considerable sweetness. But the atmosphere which we breathe is the most extraordinary of all instances: it must be surprising to those who are unacquainted with the fact, that atmospheric air, indispensable as it is to life, is composed of the same ingredients as that most violent and destructive liquid called *aqua fortis*, or nitric acid. This powerful acid, by being made to act upon sugar, the sweetest of all things, produces a substance intensely bitter to the taste. Charcoal is, of all known substances, the most difficult to convert into vapour; so much so, indeed, that the conversion has never yet been decidedly effected; it is also a very solid substance; and diamond, which is nothing but crystallised charcoal, is one of the hardest bodies in nature. Sulphur, in the solid state, is also a hard substance, and to hold it in vapour requires a high temperature. But when these two substances, carbon and sulphur, are made to combine chemically, so as to form the substance called bisulphuret of carbon, their properties are strikingly changed. Instead of the compound being hard, it is a thin liquid, and is not known to freeze or solidify at any degree of cold that can be produced. Instead of the compound being difficult to vaporise, it is of all liquids one of the most evaporable. Charcoal is the blackest substance with which we are acquainted; sulphur is of a most lively yellow hue; but the compound is as colourless as water. A new smell and taste are acquired, and, in a word, there is not one point of resemblance with the component. These facts are strikingly illustrative of the change of properties which follows on the exertion of chemical attraction between the ultimate particles of bodies.

In all the instances already adduced, it may be observed that the bodies concerned are of a different nature from each other. Thus, gold was said to have an affinity for mercury; lead for tin; tin for copper; sugar or spirit of wine for water; and air of a certain kind for lime. In fact, it is a property of affinity, that it never takes place between two bodies of the same kind: lead has no chemical attraction for lead, nor tin for tin. In a former chapter it was shown that lead attracts lead; and that two pieces of that metal, when brought into close contact, adhere with great force; but it was by cohesion. One of the chief differences between chemical and cohesive attraction is, that the former takes place only between the particles of different kinds of matter, whereas the latter takes place between particles of the same kind. If 10 particles of zinc and 10 of copper be combined, they will form 10 and not 20 particles of brass: for the attraction concerned in forming the brass is affinity, which can only join particles of a different kind; and, consequently, if there be any junction, two particles of a different kind must in each case combine to form one compound particle. Ten compound particles being thus formed by affinity, and all of them being necessarily of the same nature, although compound, these will attract each other by cohesion; for this force, and not affinity, possesses the power of joining similar matter.

We find it sometimes stated, that the attraction of cohesion is otherwise called homogeneous attraction, because it takes place *only* between the particles of the same kind of matter. There can be no greater mistake: cohesion takes place between both homogeneous and heterogeneous matter. Two thin plates of different kinds of metal may be made to cohere with great force by a forcible stroke, and this is often practised in the arts. The silvering on the backs of glass mirrors is retained by cohesion: water, whether liquid or frozen, adheres to solids by cohesion: mercury rises in capillary tubes by the same power: glue sticks to wood, and

varnish to metals, in the same manner; and there are numberless other instances.

Another great difference between cohesion and affinity is the following: — When the particles of bodies cohere, they can always be overcome by what we call mechanical force, such as pulverising, filing, &c. But mechanical force is of no avail where affinity has taken place; for let the compound be ever so completely divided, each particle of it will consist of all the ingredients which entered into the composition of the original compound, and in the same proportions, and no mechanical contrivance can separate them.

In this place it should be observed, that when a body cannot, as far as known, be decomposed into two or more ingredients, it is said to be a *simple substance;* but otherwise, it is called a *compound:* thus, copper is a simple substance; but brass, as consisting of zinc and copper, is compound. With regard to compounds, the bodies of which they are composed are said to be in a state of *chemical combination,* or united or combined by affinity, or by chemical attraction: and this state of chemical combination is contradistinguished from what is called mechanical mixture, which merely means the mixture of bodies without being attracted to each other by affinity. Thus, if filings of zinc and filings of copper be mixed by stirring them together, they are in a state of mechanical mixture; but if they be melted together, they form brass, and are said to be chemically combined. Or if a little essential oil and a little water be shaken together, they mix in such a way that the small particles of each can be seen unchanged; this is a mechanical mixture: but if a large portion of spirit of wine be poured on, they all dissolve, and the separate parts can no longer be distinguished: this is then a chemical combination. Mechanical mixture can be distinguished from chemical combination by the circumstance, that in the latter there is always a change of properties more or less complete; whereas in the former

the resulting properties are a mixture of the original ones, both being recognisable.

We have now to enquire whether or not affinity is a force of very extensive operation in nature, whether it acts in the case of certain kinds of bodies only, or whether it is a general property of matter. The facts known, seem to warrant the inference that there are no two bodies between which an affinity does not subsist, however great the repugnance apparently manifested by them for each other, and however successfully that repugnance may oppose their combination.

There are many causes which operate against affinity, and sometimes with such effect as altogether to prevent the virtual exertion of its influence. If a piece of iron and a piece of sulphur be brought into contact, no change is produced. If the iron be reduced to filings, and the sulphur to powder, and both be mixed, still no change takes place; but if this mixture be heated, they both melt, and form a substance essentially different from the original ingredients; they have, therefore, entered into a chemical combination. Here it is obvious that the combination was not effected, or, in other words, that affinity did not act, until the ingredients were melted, that is, until their cohesion was suspended: and it appears that the imperfect suspension of cohesion produced by the mechanical operation of pulverising the ingredients was not sufficient to permit the exertion of chemical attraction, until the force of cohesion was entirely overcome by the agency of heat. Hence the cohesion of the matters employed was the antagonist to the force of affinity; and until that was overcome, affinity could not act.

To take another instance: if a piece of marble be thrown into water, it does not dissolve, because the affinity between the particles of water, and those of the marble is weak, while the cohesion of the particles of the marble amongst each other is strong. But if very strong vinegar be added, the particles of the vinegar exert a stronger affinity to the marble; its cohesion is therefore

virtually less powerful, and less able to resist, and the marble begins to dissolve. It dissolves slowly, however, for the cohesion still offers considerable resistance, although it is at length overcome; but if this resistance of the cohesion be still further lessened by breaking down the marble into fine powder, the force of affinity becomes an overmatch for the much weakened force of cohesion, and the marble dissolves with facility.

In this case the cohesion is much weakened, but it is by no means completely suspended; every particle of the powder being a small aggregate resembling the original mass in properties. But a greater number of surfaces being now exposed to the action of the vinegar, greater effect can be produced by the affinity in a short time. The cohesion is never entirely suspended until the particles totally disappear in the liquid; or, as it is expressed, until they dissolve.

In the same manner, if a portion of the precious stone called sapphire be thrown into oil of vitriol, the stone is not affected, because its cohesive force is more powerful than the affinity exerted by the acid: but if the cohesive force be lessened by reducing the stone to a fine powder, the force of affinity prodominates, and the stone dissolves with facility.

In all cases where a solid dissolves or disappears in a liquid, so that the whole becomes liquid, and as transparent as before the solid was added, the resulting liquor is called a *solution*; the solid before its solution was the *solvend*; and the liquid which effected the solution is called the *solvent* or *menstruum*.

The instances which have been adduced show, that cohesion is the antagonist of affinity; where the cohesion of any two substances is strong enough, it will prevent or retard the exertion even of the most powerful affinity. On the other hand, where the affinity is weak, it may be much assisted in its efficacy by lessening the force of cohesion.

As cohesion is the antagonist of affinity, so also is affinity the antagonist of cohesion; and whenever the

former is very strong, the latter has a proportionate tendency to give way. If sugar be thrown into oil, it remains solid, because there is not sufficient affinity between the two bodies to overcome the cohesion of the sugar: but if the sugar be thrown into water, the affinity of this menstruum is so strong, that the cohesion of the sugar is broken down, and it dissolves.

Heat sometimes increases and sometimes diminishes the force of affinity. In certain cases, we find that the affinity of two bodies is really rendered more powerful by raising their temperature; in others, the affinity is apparently increased by heat, inasmuch as combinations are produced at a high temperature, which could not be in the cold; yet the increase of affinity is but apparent, and the real effect of the higher temperature, is merely to lessen the cohesion of the bodies concerned, in a manner which will be explained in the chapter on heat, and to *permit* the natural affinity to act, which existed in equal power before, although it was overpowered by the superior force of cohesion. Thus, if alum be added to cold water until no more can be dissolved, the affinity of each for the other is so far weakened, that the cohesion of the alum can be no longer overcome: but if the temperature be raised, an additional portion will dissolve with facility. In this case, the increase of temperature must be supposed to exalt the energy of affinity, rather than to lessen the resistance of cohesion; the diminution of the force of cohesion by this increase being very inconsiderable. But when we find solid substances — suppose two metals — refusing to combine at a low temperature, which evince the force of their affinity when they are melted, by the facility with which they combine, we must suppose that the chief effect of the heat was to subdue their cohesion, and thus to permit their union.

So far as to the increase of the force of affinity by heat. With regard to the diminution of affinity by increase of temperature, this effect, like the former, is sometimes real and sometimes apparent. If boiling water be poured on slaked lime, a certain portion dis-

solves, and the water acquires a certain taste: but in proportion as the water cools, more lime dissolves, and the taste becomes stronger. The same observations apply to magnesia; and water at 91° is known to dissolve more Glauber's salt, than when hotter or colder. Here then, is a direct diminution of the force of affinity by heat: but in the following case the same reasoning does not apply. Common water contains a small quantity of atmospheric air dissolved in it, and to this it owes a certain degree of the little flavour which it possesses: if the water be heated, it soon begins to discharge the air in bubbles, not because the affinity of water for air is less at a high than at a low temperature, but because the heat expands the air to such a disproportionate degree, compared with the expansion which the water undergoes, that the force of affinity is no longer able to counteract the tendency of the air to resume its aëriform state. The water, as it cools, re-absorbs and condenses a new quantity of air.

Besides the condition of cohesion, it appears, therefore, that there is a state of a very opposite nature, which antagonises the effectual agency of affinity, and which deserves some consideration. An air or gas is totally devoid of any cohesive attraction; and the distance between its particles is so great, and maintained by so powerful a repulsive agency, that there is considerable difficulty to be overcome, in many instances, before a combination can be produced. This repulsive agency, which mechanical force can overcome, is called *elasticity.* Cases will be brought forward hereafter, in which two different kinds of air that possess a strong affinity for each other, will nevertheless refuse to combine, on account of the difficulty of bringing their particles into such contact as will permit the affinity to act: yet, if the distance be lessened, as by mechanically forcing or compressing the particles nearer to each other, they will combine with facility, and even with violence. And where this cannot be done, the union may still be effected by presenting the gases to each other divested of the

repulsion which belongs to them as gases, or, more properly speaking, before this repulsive power can have attached itself to them; namely, at the moment of their generation, or while they are yet in what is called the *nascent* state.

It is true, that in these cases, heat ultimately appears to be the antagonist of affinity; not by diminishing the power of affinity, as in the case just now adduced of lime and water, but by keeping the particles of the gases concerned out of the sphere of each other's chemical attraction. Thus, *rarity* is as much an obstacle to chemical affinity as density.

But rarity does not always offer opposition to chemical union: the affinity of some gases is of so powerful a kind, that the moment they are presented to each other they combine, and sometimes to the exclusion of the heat which maintains them in the gaseous state: hence they cease to exist as gases. Instances will be given hereafter.

Having shown that affinity is a property possessed by all bodies; that every kind of matter has, in all probability, an affinity for every other kind of matter, although circumstances may prevent it from being exerted with effect, so as to produce combination; we must enquire, Are there any limits to its operation? has it a continual tendency to produce combination? does combination satisfy or lessen that tendency? or, to speak metaphorically, is it an insatiable appetency of matter for matter? A few facts of common occurrence will illustrate and answer these questions. If lime be left exposed for a length of time to the atmosphere, it absorbs from it a kind of air which is called fixed air, or carbonic acid gas. The absorption of the carbonic acid goes on progressively until a certain period, and then it ceases: thus, 100 parts by weight of lime will absorb 78½ of carbonic acid; but the lime may be exposed for ever, and it will never absorb a particle more. This combination of lime and carbonic acid is found ready-formed abundantly in nature: chalk is precisely such a compound; so also are limestone, marble, and various minerals. With regard to these

substances, all very different in appearance, it is remarkable that the lime and carbonic acid bear to each other exactly the same proportion, 78½ of the latter to 100 of the former: it is therefore apparent, that when these relative weights are present, the affinity of each for the other is satisfied, and the attraction, under ordinary circumstances, ceases to be exerted any further. When bodies combine in such a way that the affinities are satisfied, they are said to *saturate* each other.

In the same manner, the substance called potash has an affinity to carbonic acid; and, when under proper circumstances, will absorb it until 100 parts by weight of the former combine with about 46 of the latter; and then the absorption ceases, because the elastic state of the gas can be no longer overcome by the affinity of the potash, now considerably weakened. So far the affinity of potash for carbonic acid in the elastic or aërial state may be said to be saturated or satisfied; and a definite combination is produced: but, in fact, the affinity of the potash, unless under these circumstances, is not satisfied; for if its tendency to overcome the elasticity of the carbonic acid be assisted by any other power, as pressure, a new absorption and combination of it will take place.

Thus it appears that potash combines with carbonic acid in two separate portions or doses: one dose is absorbed spontaneously by the affinity of the two bodies; but this is limited by the counteracting tendency of the carbonic acid to remain in the elastic state. If the elasticity be counteracted by mechanical compression, the affinity is again exerted, and a new portion of carbonic acid, constituting a second dose, is absorbed. The quantity constituting the first dose is about 46 parts by weight; that constituting the second is nearly 92 to every 100 of potash.

There is one thing that deserves remark with regard to these two doses of carbonic acid taken up by the potash. It is an extraordinary fact, that each dose is precisely the same in quantity: so that if 46 parts of carbonic acid unite to 100 of potash to constitute its first

dose, 46 more will unite to form the second dose, and the potash will just contain twice as much in the second as in the first case. This is an important fact: it should be well understood and remembered, because it is an illustration of how combinations in general are effected where a body has an affinity to different doses of other matter. A distinct chapter will be devoted to this subject.

It has already been observed, that, as far as we know, all bodies have an affinity for each other, although there may be antagonist forces which prevent combination. We have now to enquire whether chemical attraction acts with equal force on every kind of matter.

There are three substances in common use, and well known to almost every one; magnesia, lime, and nitric acid, commonly called aqua fortis. The nitric acid has an affinity for each of the other two bodies; it has an affinity for the magnesia, and will combine with it; so also will it with the lime. Suppose, then, that these three bodies are mixed together; what will be the consequence? Will they all combine together, and form one compound consisting of the three ingredients, as would be expected from the circumstance that the nitric acid has an affinity for *both* of the other two? The result is curious and unexpected. Notwithstanding that nitric acid has affinity for both magnesia and lime, one only of these affinities is obeyed: the nitric acid attracts and combines with the lime; the magnesia is in no respect affected or acted upon: it remains untouched and separate, while the lime is attracted by the nitric acid, and combines with it to the exclusion of the other.* It must be observed, however, that this statement is only true when the quantities of each of the three substances presented to each other are equal. The phenomenon is not the less surprising; for, with even the smallest quantity of acid, its equal division between the other two bodies might have been expected.

We are now prepared to answer the question proposed

* Davy.

above, namely, whether or not affinity is equal in all bodies, or are some affinities stronger than others? The facts above detailed show that all affinities are not equally strong, and that the affinity of the nitric acid for lime is stronger than its affinity for magnesia. On account of this preference, as it may be called, which one body manifests in attracting another, such cases have been designated *elective* attraction.

We shall now suppose a case somewhat different with regard to the same three bodies. Suppose the nitric acid and magnesia to have already combined, and suppose the lime to be then added to the compound; the result will be precisely what might have been inferred from a knowledge of the former fact. The magnesia will be detached from its combination with the nitric acid; the lime will take its place, will combine with the nitric acid; and the magnesia, which had been formerly invisible, and in a state of solution in the acid, will now re-appear and remain perfectly separate. The former compound, being subverted, is said to be decompounded or *decomposed;* and the process is called *decomposition.*

Most of the great changes which are constantly taking place in nature, are instances of decomposition. It is by decomposition that the solid rock becomes covered with fertile soil: it is by the same agency that the soil throws up its verdant clothing; that growing plants are converted into animals by assimilation; that animals at length fall into decay, and return into their original state: in fine, it is by decomposition that the great natural processes of renovation and decay are kept in a state of perpetual circulation.

CHAP. V.

HEAT.

From an experiment already described*, it appeared, that if two pieces of lead are brought into contact by the application of considerable force, they are attracted powerfully, and are held together so firmly, that the weight of several pounds will be required to separate them: if the pieces are brought into less forcible contact, they do not cohere. Now, as it has been proved that they have an attraction for each other, and, as in the present case, a small force is insufficient to call that attraction into operation, it is manifest that there is some other power acting which antagonises and overcomes it, and which must itself be overcome before the attraction can operate. In short, it appears that the plates of lead, when brought together, resist the force of the hand which effects the contact, and also their own attraction of cohesion, unless the force be very considerable. The obvious inference is, that this resistance is a repulsive power exerted by the pieces of lead; which may, however, be overcome, and which then gives way to cohesion. This principle is called *repulsion*; it is the antagonist of attraction: its existence under a variety of forms is certain, and can be rendered manifest in many ways.

Attraction and repulsion being forces opposed to each other, they must very materially modify each other's agency. Yet they do so without confusion, for each has its proper limits; and we find that where one commences, the other ends; or, in other words, if attraction takes place between two particles at one distance, repulsion will take place a little further off: these distances, however, are so

* See p. 12.

small as to be insensible, and can only be known to exist by inference. There are cases of another kind, in which masses can be made visibly attractive or repulsive of each other, merely by varying the distance. Thus, if a glass rod be electrically excited, by rubbing it with silk, or, indeed, with any substance; and if it be brought near a light body, as a piece of cork, suspended by a silk thread, the cork will be attracted: in a moment after it will be repelled; but if the glass be brought with a sudden jerk close to it, the cork will be attracted; if the glass be withdrawn a little, the cork will be repelled, and so on alternately. Or a magnetised bar being freely suspended, another magnetised bar is applied to it, end to end; if they repel each other at one distance, they can be made to attract each other merely by lessening the distance. Without either asserting or denying that the agent is the same in all, these experiments are here made use of to illustrate the position, that matter exhibits attraction and repulsion at different distances; these distances being so minute as to elude our strictest scrutiny, and being only discoverable by indirect means.

The theory of Boscovich affords a representation of the constitution of matter with regard to attraction and repulsion: it is the one at present generally adopted, and it may be necessary to give a summary of that part of it which relates to our present subject. Boscovich conceives that the ultimate particles of which all matter is composed are mere points without extension, and of course incapable of being divided. These points of matter have the property of repelling each other at the smallest distances; the smaller the distance, the stronger the repulsion: so strong does the repulsion become as the particles approach very near each other, that no possible force can bring them into absolute contact. The admission of this repulsive agency becomes necessary to the theory; because, as the material particles are supposed to have no extension, there would be, but for the repulsion, nothing to prevent all the points composing a mass from being forced into one, and thus would the

magnitude of the mass be annihilated: in this sense he understands the particles to be impenetrable. As the constituent particles cannot be brought into contact, it follows that matter must be porous, however hard or heavy it may appear; and as the repulsion varies with the distance, the particles are capable of approaching to or receding from each other, or, in other words, of occupying more or less space according to circumstances. The particles being repulsive of each other, it may be asked why they do not repel each other with more effect, and separate to such distances as would cause the solid to fall to pieces. To this question the theory provides an answer. Although at the smallest distances the particles of matter are repulsive, there is a limit beyond which they are no longer so: beyond this limit an attractive force comes into operation, which prevents the dissolution of the solid state. Even the attractive force is not without its limits; for if the particles of the solid be separated a little farther from each other, the attraction not only ceases, but repulsion once more sets in. Thus do attractions alternate with repulsions, until these changes terminate in that universal attraction which is called gravity. In solids and liquids, the particles or points preserve their distance from each other by being placed in the equilibrium between the attractive and repulsive influences.

Such is the outline of the theory of Boscovich, as far as the constitution of matter is concerned; or rather, as far as the chemist is interested in the constitution of matter. The theory is much more complicated, by the multiplication of attractions and repulsions, than modern philosophy requires, remarkable as it is for adherence to facts only as guides. It will perhaps occur to the reader, that the existence of points of matter without extension, as maintained by Boscovich, Leibnitz, and others, is very difficult to understand; so intimate is the association, in the mind, of matter and magnitude, and so difficult is it to comprehend how points which

passess no magnitude can occupy space. It is vain, however, to discuss such subjects. To the student who finds it impossible to adopt opinions revolting to his ordinary habits of thought, which found their chief claims to admission on the difficulty of disproof, it may be some satisfaction to observe, that the evidence on the subject cannot be of a very convincing kind, when we find Leibnitz asserting that the particles of matter have no extension; Descartes maintaining that extension is their only property; Locke defining an atom to be "a continued body under one superficies;" and Berkeley denying that matter exists at all. It is fortunate for the chemist, that a knowledge of the ultimate mechanism of matter is not necessary to the prosecution of his researches; although it must be admitted, that certain hypotheses respecting the ultimate molecules of matter may assist his imagination in conceiving several of the most interesting natural phenomena.

Whatever the nature of repulsion may be, it is found to be in some manner connected with what we call *heat*: corpuscular repulsion is found to be increased by the presence of heat, and diminished by its absence. When heat increases the repulsion between the particles of a body, these particles must recede farther from each other in all directions; and if they all take more remote stations, it is obvious that the bulk of the body must be increased: it is now, in fact, larger, although the quantity of matter remains the same, and it is said to be *expanded*. On the other hand, if a diminution of heat lessens repulsion, the attraction of cohesion is permitted to exert itself with more force. the particles of a body thus cooled will draw nearer to each other; the body will consequently occupy less space, although the quantity of matter remains the same; and the body, in this case, is said to be *contracted*.

From the constant and evident association of heat with repulsion, philosophers have at length conceived that they are both effects of the same cause. As to the

nature of the cause there has been much difference of opinion. Some suppose that heat is matter of a peculiar nature; others conceive that heat is a condition of matter, and that it consists in a vibratory motion of the constituent particles of bodies. It is a question of great difficulty, but of little importance.

Be this as it may, the language of the material hypothesis of heat being so much more convenient and intelligible than that of the undulatory hypothesis, we shall use the former in preference.

Heat is admitted by the philosophers of the present day to be the principle concerned in repulsion: and heat and cold are known to produce expansion and contraction in all bodies. Heat is, therefore, the antagonist of cohesion. Chemists have thought it necessary to make a distinction between the senses in which the word heat may be taken. In its usual acceptation, it merely means the effect excited on the organs of sensation by a hot body. But as this must be produced by a power in the hot body independent of sensation, that power is what chemists understand by the word *heat*: and to distinguish between the effect and its cause, the term *caloric* has been substituted. The introduction of this term appears altogether unnecessary, when the sense in which the word *heat* should be understood is explained. Caloric means the *cause* of the *sensation* heat: and there seems no reason to fear that the perception of heat by the organs of sensation can ever be misunderstood to be the agent in chemical phenomena.

The first question that occurs with regard to heat is, Where is its abode? where does it proceed from? The answer to these questions is, that it exists every where; and can be obtained from every thing.

It is easy to prove that all bodies, whether solid, liquid, or aëriform, contain heat, even when they appear to our sensations to be absolutely cold. They can be subjected to such processes as will cause its evolution;

and hence it is inferred, that these bodies must have contained heat throughout their substance in a latent and insensible state.

If a piece of soft iron, at the common temperature of the atmosphere, be struck smartly on an anvil with a hammer a few times, it becomes hot; and if the hammering be dexterously continued for some time, the iron may be heated red hot. It is common among smiths to procure fire in this way. By rubbing two pieces of dry wood together, so much heat may be generated as to set them on fire; and this mode is resorted to by savage nations. In rubbing even two pieces of ice together for some time, they will gradually melt; which proves that heat must have been evolved.

The instances that can be adduced of the extrication of heat are by no means confined to solids: there are various fluids, which, when mixed, undergo a considerable elevation of temperature: such is the case, for instance, with oil of vitriol and water: and if a quantity of that liquid called nitric acid be poured on oil of turpentine, the mixture bursts out into flame. Hence a considerable quantity of heat must have existed in one or both of these liquids, in a quiescent state.

That heat exists in airs or vapours is equally demonstrable: there are instances of the quantity being so great as to produce ignition and flame. Thus, let a brass tube, close at one end, of about a quarter of an inch diameter, and very even in the bore, be fitted with a piston, well leathered like the piston of an air-pump, so that when it is forced down the tube no air can escape. Then let a bit of the fungus called *agaric*, about a fourth part of the size of a pea, and well dried, be thrown down into the bottom of the tube, and let the piston be introduced. If the air in the tube be now compressed by powerfully forcing down the piston with a sudden strong stroke, so much heat will be extricated from the air that the agaric will ignite. A philosophical toy of this kind is now commonly sold. An intense

flame, may be instantaneously produced by mixing two airs, which will be described hereafter, called phosphuretted hydrogen and oxygen.

That bodies contain heat would, however, be sufficiently proved without the preceding experiments, merely by showing that, under ordinary circumstances, they can be made colder; or, in other words, that heat can be abstracted from them; which could not happen if they did not contain it. The force of this reasoning certainly depends on the truth of the involved position, that cooling a body is the same as withdrawing heat, and that cold is merely the absence of heat. This is the opinion of philosophers at present: but the reverse has been maintained, and striking experiments have been brought forward to support the opinion that cold is an agent of a distinct nature from heat, and not merely the absence of it; but they have failed in proving their object. The Florentine academicians placed a mass of ice, weighing 500 pounds, before a concave glass mirror, in the focus of which was a sensible thermometer. The spirit of wine in the tube immediately began to subside; and when the mirror was covered, the spirit rose again, proving that the depression of the thermometer was not attributable to the proximity of the ice. From this, and similar experiments, it has been by some inferred that cold is matter *sui generis;* but the doctrine has few if any adherents. If we consider the process which causes the rise of the thermometer when a heated body is before the reflector, and if we admit that cold is the absence of heat, then, by supposing the course of the calorific rays from the heated body to be inverted, we find that ice should depress the thermometer, inasmuch as the thermometer then becomes the source of heat instead of being its object.

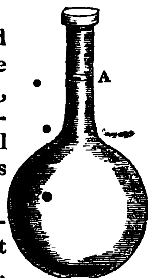
As all bodies contain more or less heat at all temperatures which the world ever experiences, and as a portion can be withdrawn from them, or added, it becomes

a question, what are the effects produced upon the body by the loss or by the addition.

If heat be the principle of repulsion, and the antagonist of cohesion, the consequence must be, that, by withdrawing heat, the attraction of cohesion will be allowed to act with more energy; the particles of the body cooled will be drawn nearer together; and if so, the total bulk of the body must be diminished. Hence, the effect of cooling is to diminish bulk. If a body, in consequence of being cooled, has its particles brought nearer together, there will be a greater number of particles in a given bulk than before. Thus, if a bar of iron, 10 inches long, could be so far reduced by cold as to measure but $9\frac{3}{4}$ inches, it is obvious that any given inch of the bar, in its contracted state, must contain a greater number of particles of iron than before. The quantity of matter in any given bulk of a body, as has been already explained, is called density, or specific gravity; and it follows, that in the case of the bar of iron, its density or specific gravity is increased by cooling, because a greater quantity of matter is brought into a smaller space. And it may be received as a general law, which, however, is not without exception, that the effect of cold on all bodies is to lessen their bulk and to increase their specific gravity. Conversely, it might easily be anticipated that, by adding heat, the repulsion of the material particles would be increased, the bulk would be increased, and the specific gravity diminished: this, accordingly, is found by experiment to be the case; and the law applies to matter, whether in the solid, liquid, or gaseous state. The expansion of solids and liquids for equal additions of heat is not always equable; when at a high temperature, a further addition of heat will cause greater expansion than at a low one: but this does not apply to gases; they expand equably.

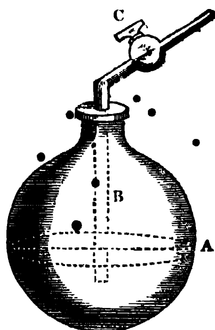
The expansion by heat, and contraction by cold, of bodies in the solid, fluid, and aëriform state, is easily shown by experiment.

A bar of iron, made to fit into a gauge, with ease, when cold, will, when heated in it, no longer fit it, but will become so large, that it cannot enter it. On being cooled, it will resume its former dimensions, and again fit the gauge. If the bar be made to fit the gauge, at a temperature approaching to redness, so as to remain fixed, it would drop out when cooled. In this experiment, however, it is important that the temperature of the gauge itself should not be changed.



If a glass flask with a long neck, and filled to A with cold water, be heated, the water will begin to rise in the neck, and, after some time, the vessel will be completely full: when cold, the water will fall back to its former level. This involves the principle of the thermometer.

If an air-tight metallic vessel, containing water as high as A, all the rest being filled with air, and having a tube, B, descending into the water, furnished with a stop-cock at C, be heated until the air become hot, its tendency



to expand will increase its elastic force so much that it will press so strongly on the surface of the water, that when the stop-cock is opened, a jet of water will be

projected to a great distance. When cold, the air will shrink to its former volume; and if the stopcock be opened while its jet-pipe is immersed in water, a quantity of water will rush in, to supply the place of that which the air had expelled. A bladder partly filled with air, if held before the fire for some time, will appear full; but, on cooling, it will shrink to its original bulk. Air and all vapours and gases expand by heat equally: the rate is $\frac{1}{480}$th part of their whole bulk for every degree of the thermometer.

In all these cases, the addition of heat caused expansion, whether the body concerned was solid, liquid, or aëriform; and its abstraction occasioned diminution of volume. But diminution is not caused alone by the abstraction of that quantity of heat which had been added. If the body be cooled lower, for instance, much below the natural temperature of the surrounding medium, the particles composing the body approach still nearer each other, and the contraction increases.

As expansion and contraction are, with a few exceptions, invariable results of increase and diminution of heat, expansion has been made use of as the measure of heat, and the principle is adopted in that simple instrument called the thermometer. The thermometer is no more than a glass tube of very small bore, with a bulb blown on its end. The bulb and part of the tube are filled with mercury; and when heat is communicated to the mercury, it expands and rises in the tube. The height to which it rises is the measure of the heat; or, in other words, the more or less the mercury rises, the greater or less is the intensity or *degree* of the heat. A scale is affixed, on which different degrees are engraved; of these degrees, two are the representatives of certain remarkable phenomena constant in their agency and immutable in their period of occurrence, namely, the points at which, under certain circumstances, distilled water freezes and boils; all the rest are arbitrary divisions of the space between these two invariable

points. Different divisions are adopted in different countries; a circumstance to be lamented, as comparison of temperatures thus becomes inconvenient.

Water, at certain temperatures, furnishes an exception to the law of expansion by heat, and contraction by cooling, which is well worth consideration. If a glass flask, with a very long neck, be filled with pure water at 60° to the middle of the neck, a thermometer being immersed; and if some of the means hereafter described be used for gradually reducing its temperature; it will be found that, in proportion as the water cools, it contracts and sinks in the neck, until the thermometer arrive at 39½°. The cooling process being continued, the water, instead of contracting still more, begins to rise again in the neck, and continues to do so until the water freezes, and then it suddenly expands much more. Thus 39½° is the thermometric degree at which water is at its maximum density; above or below that, its density diminishes: and hence it is obvious that ice is specifically lighter than water: this is the reason that ice floats on water. Dr. Thomson found its specific gravity 0·92, that of water being 1·00.

The expansion of water in the process of freezing was discovered by Paulo del Buono, an Italian philosopher; and the fact was published by his associates of the *Accademia del Cimento* (Society for Experiment). This has been long known; but it has escaped observation, that these academicians had also made an experiment which evinced that the maximum density is above the freezing point, although they drew a wrong conclusion from it; and of this any one may convince himself, by considering the experiment detailed at p.106. of their Transactions. They also proved the enormous force with which water expands in the act of freezing: spheres of glass, silver, and gold, were burst by the contained ice. A sphere of brass was burst in this manner, which Muschenbroek calculates to have re-

quired a pressure from within equal to 27720 pounds. Other striking results have since been obtained.

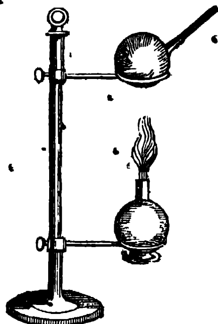
It having been already shown that the addition of heat expands bodies, and that its abstraction diminishes them in volume, it follows, as a necessary consequence, that heat lessens density, and that cold increases it. If a vessel be filled to its brim with cold water, and heat applied, the vessel soon begins to overflow, because the water expands. When the water comes near its boiling point, the vessel still remains full, although much has left it. The particles of the water must, then, have been repelled by the heat to greater distances from each other. But if the vessel, now full of boiling water, be allowed to cool, the water shrinks below the brim of the vessel; for the heat or repulsive quality being dissipated, the particles of the water resume their original distance from each other. The consequence is, that hot water weighs lighter than cold, the bulks being alike; as is easily proved by pouring a pint of boiling water into one basin of a pair of scales, and a pint of cold into the other; the latter will preponderate. It is but another mode of expressing the same fact, to say that hot water is specifically lighter than cold water: and the position is equally true with respect to all bodies, whether solids, fluids, or airs. The change of density, according to the change of temperature, is easily proved. Let a hollow glass ball be so prepared that it barely sinks in a vessel of water at the temperature of 60°. If iced water be poured in, the density is increased by the cold, and the ball, now specifically lighter than the water, ascends to the top. If hot water be added, the density is lessened; the ball, rendered specifically heavier than the water, sinks to the bottom; and it may be made to rise and fall alternately.

The foregoing considerations enable us to obtain some insight into the structure of matter, and to appreciate the value of Boscovich's theory, so far as it need be applied to the facts which have come under ob-

servation. It was shown, when noticing the theory of that philosopher, that the particles of matter are supposed to be repulsive of each other at small distances; attractive at distances a little greater; and at still greater distances, once more repulsive. It appears that the repulsive agent concerned is caloric, and that its operation is a counteracting force to the attraction of cohesion. Solidity is, therefore, expressed by the following condition: — the constituent particles of matter are kept at a certain distance from each other by two forces; cohesion, which draws them together, and calorific repulsion, which keeps them asunder; and their actual distances from each other are precisely between the limits of the two forces: this is the equilibrium of Boscovich. The addition of artificial heat, by increasing the repulsion between the particles, must augment the bulk of the solid, the cohesive force being so far weakened; and the abstraction of heat, by lessening the repulsion, must permit the cohesive force to act with more energy. It may, therefore, be laid down as a truth, well ascertained, that the effects of caloric and of cohesive attraction are opposed, and constantly antagonise each other. I am not aware that the following facts, which are highly illustrative of the subject, have been observed by others. At page 12. a figure is given, representing two pieces of lead, with a scale-pan and weight attached, showing the force of the cohesive attraction. If, while the scale-pan is well loaded, the pieces of lead be heated, their attraction is lessened by the repulsive agency exerted by the heat, and the lower piece falls off. The most convenient mode of heating the two plates of lead is, to direct a jet of burning hydrogen, pressed from a bladder furnished with a stop-cock and pipe, upon the junction of the plates. The heat need not be very great.

If a wire of zinc, about 2 inches long and $\frac{1}{10}$th of an inch thick, be supported at both ends, while a long wire hangs from its middle, sustaining about 7 avoirdupois pounds; and if, in this state of things, a flame be held under the zinc, its attraction of cohesion

will be so far antagonised by calorific repulsion that the zinc will first bend a little, and then suddenly break in two; but there will not be the least symptom of fusion. If an empty glass globe, with a long neck, be set on a



polished brass ring of a chemical stand, on which it merely rests without fitting down into it more than an inch, the neck forming an angle of about 45° with the horizon, it will remain in that position while it is cold. But if a voluminous flame of a spirit lamp be applied far below, yet so as to heat the globe and the ring, such a repulsive force will be generated between the glass and the brass, and their contact with each other will be so far lessened, that, after some time, the long neck will fall down, provided that the original posture of the globe was balanced so exactly as to be overset by the smallest disturbance. If a few drops of water be let fall on a very hot iron plate, they glide over it in all directions with amazing volubility; and they do not adhere to it as they would were it cold: for repulsion acts between them. Or if ardent spirit be made to boil gently in a glass flask, globules of perfect sphericity will dance over the surface without coalescing: for they repel each other as well as the surface over which they glide; and they are spherical, owing to the cohesion of the liquid, which is not counteracted by any attraction from the surface

beneath. If a small disc of tin plate be hung from its centre by a wire, and if a similar disc be made to adhere to the under surface of the former by the interposition of a few drops of water, and pressing the discs moderately until they adhere, they will remain in contact. But when the heat of a spirit-lamp is applied underneath, the cohesion of the water will be so much weakened, that the lower disc will immediately fall off.

The expansion produced in bodies by the addition of *some* heat, and the condensation or contraction occasioned by its abstraction, having been so far investigated, it is next to be enquired what other effects may be produced upon matter, in its three states of existence, by a further addition or subtraction of heat.

If a piece of lead be heated, the first effect of the repulsion is to produce expansion and diminution of density: the heat continuing to increase, the particles of the lead continue to repel each other more and more; until at length they are so far separated as greatly to weaken their attraction of cohesion: hence, the solidity of the lead is broken down and it melts. If the melted metal be allowed to cool, the heat or repulsive power is withdrawn, and the cohesive attraction of the particles of lead is permitted again to exert itself: hence the particles are drawn together more and more as the heat is dissipated; and at length, when the lead is cool, the particles have arrived at that contiguity to each other which constitutes solidity, and the metal is as hard and as dense as before.

In this instance, the heat necessary to liquefy the lead was necessarily considerable: but there are other bodies which, under ordinary circumstances, are always liquids, as water; yet the analogy still holds: for, as the liquidity of lead is caused by heat, so also is that of water: if its temperature be sufficiently reduced, it will become solid ice; and the only difference is, that water requires to be cooled much lower than lead before it solidifies.

The melting of ice is, therefore, explicable in the

same manner as that of lead; the first effect of the heat is to cause repulsion between the particles of the ice, and this goes on until the repulsion almost balances the attraction of cohesion; then the solid ice breaks down into water.

If we continue the application of heat still further, the same process of expansion goes on; the particles of water, as the heat increases become more and more repulsive of each other; and at length the balance between attraction and repulsion is subverted, the attraction is overcome, and the repulsion prevails over its antagonist force. When this happens, the watery particles at once expand themselves so far asunder as to alter altogether the state of the water, which now is converted into what is called *steam*, or *vapour*; and the more this is heated, the more it expands, unless it be confined.

Steam, while hot, is in a state very like that of the atmosphere: its particles are at a much greater distance from each other than those of water. If these particles be brought nearer each other, either by removing the heat which is the cause of their repulsion, or forcing them to approach by mechanical pressure, they coalesce, and the result is water.

It appears, therefore, that water is capable of undergoing three different changes, by being made to contain three different quantities of heat. It may exist in the state of a solid, a liquid, or a vapour or air. In the same manner various metals, sulphur and a vast number of bodies, are capable of assuming these three states, according to the degree of heat: and it is not only under some one or other of them that all the bodies in nature exist, but it is supposed that every kind of matter is capable of assuming each of the three states, although as yet we do not, in every case, possess the means of communicating heat sufficient for the purpose.

The sum of the preceding statements is, that all bodies contain a certain portion of heat, which, being natural to them, is insensible unless called forth; that if to a solid a sufficiency of heat be communicated, it melts and

becomes a fluid. If another portion of heat be added, the fluid boils away, or evaporates in the form of a vapour, or gas. The question then occurs, If bodies be deprived of their heat, do they pass retrogressively into the other states? and the answer must be affirmative, provided the bodies can be sufficiently cooled. Thus, a solid that has become liquid by heat, will again become solid by cooling; and a vapour, if cooled, will become liquid or solid, according to its nature. But there are some vapours which cannot, by any attainable degree of cold, be made to change their form: these are what are called permanent gases, of which the atmosphere is an instance. When a body becomes solid, which was not previously so, no matter how the change has been effected, the heat that constituted the previous state is liberated. When a gas becomes a fluid or a solid, heat is always liberated and rendered sensible: and heat is also liberated when a fluid becomes a solid. These important laws can be illustrated by experiments easily executed.

The substance known in the arts under the name of sal ammoniac is a hard, white solid, having a crystalline texture. Notwithstanding the hardness and heaviness of this substance, it is composed of two different kinds of air, or, as chemists call it, gas; and it is easy for even the inexperienced to resolve it into its two constituent gases, by processes which, although he may not as yet understand, he can execute. These gases are known to chemists by the name of muriatic acid gas and ammoniacal gas. If powdered sal ammoniac be mixed with oil of vitriol in a common phial bottle, the phial will shortly be filled with vapours. If a cork be adapted to the phial, and a slender glass tube be fitted tight in a hole bored through the cork; and if another phial, perfectly dry, be inverted over the former, so that the glass tube passes up a few inches into it, the vapour will enter the second bottle: after some time, it will expel all the common air with which the bottle was originally filled; and the bottle will now contain nothing but mu-

riatic acid gas. If a bit of ice be thrown into this bottle, and the bottle corked, the ice will immediately melt, and the gas will all disappear. That it has disappeared may be proved by suddenly drawing out the cork; for common air will rush into the bottle with such violence, that a slight report will be produced. The muriatic acid gas has, in short, entered into the ice—it has lost its form of gas—it has become a liquid; and, in so doing, it has parted with the heat which caused it to be a gas; the liberated heat entered the ice, and melted it into water. The experiment can be made in a much more elegant and convincing manner; but to do so would render the description complex and the execution troublesome.

The other constituent gas may be separated from sal ammoniac by mixing its powder with a little slaked lime, heating the mixture in a bottle, and inverting a dry empty bottle over the glass tube, as before. If a bottle filled with muriatic acid gas, and another with ammoniacal gas, be closely applied mouth to mouth, so that the two gases can mix, but not escape, it will be found that, from being transparent and colourless like common air, they will, in mixing, immediately change to a dense white cloud, at the same time that the bottles will become warm. After some hours, the white cloud will subside into a thin, solid coating on the sides of the bottle, which is, in fact, the original sal ammoniac, regenerated from its two constituent gases. Thus, the gases, when mixed, pass from the gaseous to the solid state; in doing so, they both part with the heat which caused them to be gases; and this heat is so great as to warm two considerable masses of glass. We have now to exemplify the case of a fluid passing to the solid state.

A familiar instance is the slaking of lime. If on a piece of well-burnt roche-lime, its bulk of cold water be poured, it will be soaked up, and the lime will appear as dry as ever. In a few minutes the lime will swell up, burst, and become hotter than boiling water, and

clouds of scalding hot steam will arise from it. In this case the water lost its fluidity, and formed a dry powder with the lime; the heat which caused the water to be a fluid was extricated, and it was sufficient to raise the temperature of the whole mass considerably.

The last instance which shall be adduced is an analogous one, and is that of a solution of Glauber's salt in a glass globe, described at page 19. This liquid, as has been already mentioned, will not crystallise, or pass into the solid state, until the vessel is shaken or opened, or the surface of the solution touched: it then suddenly becomes solid, and the temperature rises.

Conversely, when a solid becomes a fluid, or when a fluid becomes a vapour, or a gas, it might, from the foregoing facts, be anticipated that heat would disappear: it accordingly does; and so much of it is absorbed and concealed, that the bodies concerned become colder than before.

Thus, let 1½ pound of newly crystallised common Glauber's salt be reduced to fine powder and thrown into a thin glass basin, with 15 ounces of muriatic acid, and let the whole be immediately stirred round with a glass rod: the powder, from being a solid (for its particles are solid), dissolves, — that is, passes to the fluid state, — and this it could not do without receiving a supply of heat. The supply is withdrawn from the whole contents of the basin; hence their temperature is reduced; and so cold does the mixture become that a tube closed at one end, filled with water, and immersed in it, will immediately freeze, even during the heat of summer. The heat thus withdrawn has entered into the solid particles of Glauber's salt, or the solid water contained in it, and they, in consequence, have assumed the liquid state; while the heat is concealed or absorbed in some way that is not easily comprehended. Or, if snow, and half its weight of common salt, be suddenly mixed, they immediately become liquid: and the mixture, if the ingredients were originally at the freezing point, will be reduced to 32° or

40° below it. Professor Braun froze mercury with a mixture of snow and nitric acid. The same absorption of heat takes place with certain metallic mixtures: if 207 grains of lead, 118 of tin, and 284 of bismuth, all in filings, be mixed with 1617 grains of mercury, the temperature will be lowered from 64° to 18°.* It is only some metals that answer this purpose. When gold and mercury are combined, heat is produced. (*Oldenburgh, Philosoph. Trans., No.* 122.)

The most common instance of the conversion of a fluid into a gas is evaporation; and to prove that heat is withdrawn from the bodies concerned, and cold produced, a simple experiment will suffice. If some strong ether be poured on one's hand, it instantly evaporates,—that is, changes to the state of vapour; and as in order to do this, it must derive a supply of heat from some source, it does so from the hand, and there is a sensation of intense cold produced. Persons who have not made such subjects a part of their study, are apt to conceive that there is an inherent coldness in the ether, and they are the less surprised. The following experiment seems sufficient to remove so erroneous a notion. Let a thermometer be plunged into a phial of ether for a short time; no change takes place, proving that the ether possesses no natural coldness: but let the thermometer be taken out, and instantly the mercury begins to sink, evincing that the cold was produced by evaporation from the bulb. If a very thin glass tube, closed at one end, and filled with water, be wrapped round with muslin; and if the tube be frequently immersed in strong ether, allowing what the muslin soaks each time to evaporate, the water in a short time will be frozen. Blowing *warm* air on it will even hasten the cooling, because it promotes the evaporation. By wetting the bulb of a thermometer constantly with ether, and blowing on it with a bellows, Dr. Franklin sank it 25° below freezing †; and even without blowing, Cavallo sank it 4° lower. ‡

* For the production of cold, Mr. Walker, formerly an apothecary at Oxford, has given various formulæ of freezing mixtures.

† Experiments and Observations, p. 364. ‡ Philosoph. Trans. 1781.

On the principle of evaporation, coolers for wine or water are commonly constructed. A vessel made of porous earthenware is filled with water, which, by soaking through and evaporating, keeps the water and any thing immersed in it cold. The porous vessels so generally used in Spain, called *alcarrazas*, were introduced by the Arabians. In warm oriental countries they have been used for centuries.

As evaporation takes place much more rapidly in the receiver of an air-pump when the air is withdrawn, the cold produced is the greater: but the watery vapour must be continually removed by the constant action of the pump, which is a difficult and imperfect mode. Leslie obviated this, by introducing some substance which absorbs watery vapour rapidly, as strong sulphuric acid, or certain earthy substances. In this way, by exposing a thermometer coated with ice, he promoted the evaporation of the ice so rapidly that the mercury froze. Professor Configliachi, of Pavia, also froze mercury by the evaporation of water.

In some cases, where a gas or a vapour is formed or extricated from a liquid, although cold is actually produced, it is not sensible; for an approximation has taken place between the particles of the liquid; it has become more dense, and even this approach to solidity causes an extrication of heat which counterbalances the cold, and hence the temperature is scarcely changed. This happens, for instance, in the case of mixtures of substances, which occasion that kind of apparent boiling in the cold called *effervescence*,—as when dilute oil of vitriol and common magnesia are mixed fixed air is developed, the necessary heat being derived from the liquid, which hence would become colder, but that it has suffered an increase of density. The liquor is now less fluid, that is, as might be said, more solid: heat is the consequence, and this supplies the place of the heat which had been withdrawn by the evolution of fixed air. Indeed, there can be little doubt that in all cases in which cold is produced during sudden liquefaction, and in which an in-

crease of density happens, the degree of cold is rendered less intense on account of being counteracted by the evolution of some heat occasioned by the increased density. Such must be the case in the production of cold from concentrated nitric acid and snow.

From the foregoing statements it appears that heat has the effect of expanding, or, as it is called, rarefying all bodies to which it is applied; that the series of changes of form produced by this rarefaction is from the solid to the fluid, and then to the aëriform state. A solid exposed to heat first expands, and then becomes a fluid: the fluid then expands, and at last in an enormous ratio, and becomes a vapour or gas; which, if further heated, still further expands: but no other change of state happens beyond this. The converse changes are the contraction or condensation of a vapour by cold; a sudden contraction in an enormous ratio so as to form a liquid; a further contraction into a solid; and this may be still further contracted by a greater cold.

It appears also, that during this series of changes of form, heat is either absorbed and concealed, or liberated and rendered sensible.

Notwithstanding, when a solid is about to become a fluid, or a fluid a gas, the caloric, which is to constitute and be concealed in a new state, must previously pass into the body in a sensible form; and the process by which it becomes quiescent, and afterwards sensible, is extremely curious.

We shall take water as the body in question, as it is easily made to assume the three states — ice, water, and vapour. If a thermometer have its bulb bedded in a piece of ice, the instrument will indicate the temperature of the ice: suppose it to be at that time 20°. Bring the thermometer, still immersed in the ice, into a warm room, the temperature of which is, perhaps, 70°, it begins to rise, indicating that the ice is receiving caloric from the surrounding warm air. The thermometer continues to rise, until it stands at 32°: until this period the ice remained hard and dry; but at 32° it becomes

moist, begins to melt, and this melting process goes on until it is liquefied. Meanwhile the thermometer, which rose progressively until it arrived at 32°, stops there; and, all the time that the ice is slowly melting, remains stationary at that degree; notwithstanding that another thermometer, hung up in the room, indicates the air to be still 70°. As soon as the whole of the ice is melted, the thermometer immersed in its water begins to rise; and it continues to do so from 32° until it arrives at 70°, which being the temperature of the room, it can rise no higher. It should be observed that while the ice is melting, both the ice and the water are at the temperature of 32°; and the water remains at that degree while there is any ice unmelted.

From this experiment, we may reason as follows: — When the ice at 20° was exposed to an atmosphere of 70°, the heat of the air in the room entered into the ice, and raised its temperature until the thermometer stood at 32°, when it became stationary. The first question that occurs is, Why did the thermometer remain stationary? can we suppose that the heat of the atmosphere ceased to enter into the ice? Such a supposition must not be admitted; for then no reason could be assigned for the continued melting of the ice, and for the rise of the thermometer from 32° to 70°, after the whole was melted. The only other way in which the question can be put is, Did heat continue to enter the ice, although it had not the effect of causing a rise of the thermometer? It can be shown that this is the truth. As soon as the ice rose to 32° it began to melt, and continued to do so until it was all melted, when the thermometer again began to rise, because heat continually entered the ice; but, during the change from the solid to the liquid form, it was so concealed in the substance as to be incapable of affecting the thermometer. Heat continued to enter until as much was absorbed as was necessary to convert the whole into water; when, there being no longer any ice to render the concealment of caloric necessary, the latter entered, became sensible, or free, and then affected the thermo-

meter. However difficult it may be to conceive how heat can be entering into the ice at the moment of melting without raising its temperature, it is certainly true, and can be proved by a very satisfactory experiment. Take a pound of ice, broken small, at the temperature of 32°, which it will exactly reach if exposed to a somewhat higher temperature, until it begins to grow a little moist; to this pound of ice, add a pound of water heated to 172°; mix them together: the ice immediately melts, and reduces the temperature of the water from 172° to 32°, which was its own original temperature. What, then, has become of the 140° of heat lost by the hot water? There is no other way of explaining it, than by admitting that this quantity of caloric has entered the ice, has become concealed in it, was just sufficient by its concealed existence to convert that much ice into water, and was the exact quantity which would have raised an equal weight of water 140°, although it did not heat the ice at all.

Perhaps the following experiment is still more strongly illustrative of this doctrine: — Take a pound of water at 32°, and a pound of water at 172°; mix them, and the resulting temperature will be found 102°, the arithmetical mean, or midway number; for one has lost as much as the other gained. But substitute an equal weight of ice at 32° for water at 32°, and the resulting temperature will be still 32°. The difference, therefore, between a pound of water at 32° and a pound of ice at 32° is, that the former not only contains as much heat as the latter, but such an additional quantity as would be adequate to heat another pound of water 140°, although it is concealed.

It appears, therefore, that when ice arrives at 32°, and the thermometer ceases to rise, a great quantity of heat must enter it before it can be converted into water: and that whatever heat is required to raise ice at 31° to water at 32°, is vastly greater than what would be necessary to raise water from 32° to 33°, or ice from 31° to 32°; and, to conceive the change more precisely, it must be

understood that the whole quantity of caloric thus required is employed in converting ice at 32° into water at 32°.

Were it not necessary to the liquefaction of ice, that a large quantity of heat should be absorbed; and were the opinion true, which prevailed previously to the era of Black, that the change of ice at 32° into water requires but a very small addition of heat; the consequences, says that celebrated philosopher, would be dreadful: torrents and inundations arising from the sudden melting of snow and ice would be irresistible; they would tear up and sweep away every thing,—and so suddenly, that mankind could have great difficulty to escape their ravages. It is the same slowness of liquefaction, he observes, which enables us to preserve ice in summer in ice-houses; and the melting is still further retarded by the difficulty which external heat experiences in penetrating the building. Snow continues on many mountains during the whole summer in a melting state, but melting so slowly that the whole of that season is not a sufficient time for its complete liquefaction.—(*Black's Lectures*, i. 118.)

Mercury in this respect resembles water in its habitudes. A mass of frozen mercury, with a thermometer included, if brought into a warm room, will rise to 39° or 40° below zero, and remain so during the whole time that the mercury is melting; for this is its freezing point.

Let us now follow up the original experiment a little further. The ice having been all melted, and the thermometer having ascended from 32° to 70°, which is the temperature of the room, no further increase of temperature can take place unless artificial heat be communicated. If the heat of burning fuel be applied, the thermometer again begins to rise, and at length reaches the temperature of 212°. But here it stops; and, as happens in the case of the melting ice, no heat that can be applied will raise it a degree higher. A new process now sets in: bubbles form in the bottom of the vessel next the source of heat; they rise to the surface, break, and

discharge steam, which is, in fact, a gas composed of particles of water united with caloric, and so highly repulsive of each other as to occupy no less than 1720 times * more space than the original water. Hence its extreme lightness and thinness or rarity. This formation and discharge of steam-bubbles constitutes what is called the *boiling* of water.

During this process, the steam forms continually; and its temperature, as well as that of the water, is continually 212°: the water, therefore, when it arrives at that degree, undergoes a change of state; calorific repulsion overcomes the cohesion of the water; steam is formed; and all further addition of heat enters into the same kind of concealed existence as it does in melting ice, and instead of raising the temperature, is expended in forming steam until the whole of the water is boiled away. But, after this absorption and consequent conversion into steam, heat may be applied with effect, and

* This determination is so different from what is inferrible from the experiments of Gay-Lussac, viz 1297·3 at 60°, and 1689 at 212° (see *Thomson on Heat, &c* 202), that it is necessary to explain the manner in which I deduce it. My calculation is founded on the supposition that two volumes of hydrogen and one of oxygen contract into two volumes when they combine; and this is the only supposition that is compatible with the direct experiment made by Gay-Lussac on the expansion of water into steam. The other elements are the specific gravities which I hereafter assign to oxygen and hydrogen, for reasons stated, and the weight of a cubic inch of water lately adopted by the legislature, viz. 252·458 grains at 62°; or, corrected by Gilpin's tables, 252·5097 grains at 60°.

200 cubic inches of hydrogen =	4·2394 grains.
100 - - oxygen =	33·9153
	2) 38·1547
	19·0773

Hence 19·0773 : 100 : : 252·506 : 1323·594.

A cubic inch of water at 60° would, therefore, expand into 1323·594 cubic inches at 60°—we may so consider it for the calculation: and this, heated to 212°, would expand into 1719·786 cubic inches. The specific gravity of steam at 212° is, therefore, 0·4768 compared with air at 60°; and 100 cubic inches of it weigh 14·6827. The specific gravity of steam compared with air of the same temperature as itself is 0·6191: and 100 cubic inches of steam at 60° would weigh 19·0773 grains.

If this calculation be well founded, professor Robison's estimate, averaged from Mr. Watt's experiments, that a cubic inch of water forms a cubic foot (1728 cubic inches) of steam at 212° is very near the truth. But Dr. Black says, " more recent experiments by Mr. Watt make 1720 or rather more, but he is not perfectly precise in his opinion."—(*Lectures*, i. 207) This is exactly my estimate, and the coincidence between calculation and experiment is very striking.

the steam, by being enclosed in a proper vessel, may be made to raise the thermometer higher in proportion to the heat applied.

Thus, in the heating of water between the temperatures of 32° and 212°, there are two distinct stages at which remarkable phenomena happen. At 32°, the thermometer remains stationary, and will not rise a degree higher while any ice remains unmelted: after this, it ascends until it arrives at 212°, where it again remains stationary.

All the time that the thermometer stands still, heat is accumulating and becoming concealed; during the first stage in the water produced, and during the second in the steam: and the heat that is thus accumulated and concealed is what constitutes the fluidity of the water and the vaporific form of the steam; hence the terms *caloric of fluidity*, and *caloric of vaporisation*, which merely mean the concealed heat of water and steam. It is, therefore, no more than what might be expected, that water contains much more heat than ice, and steam much more than water.

Although it has been stated that water cannot be heated beyond 212°, on account of the change of form which it undergoes and its conversion into steam, this statement is only true under certain limitations; it is necessary to the production of such effects that the steam should have liberty to escape. If it be under sufficient constraint and cannot escape, and if the containing vessel be full of water, steam will not be formed; the water must then sustain all the additions of heat, and its temperature must rise proportionately. In this way the water may be raised to any temperature, provided that the vessel is close and sufficiently strong to resist the violent effort which the water would make to form steam. According to Muschenbroek, lead melts in the water of a Papin's digester when the water is heated under due pressure. Lead melts at 612°. When water under pressure is considerably heated, if the restraint be removed there will be a sudden formation of steam; a

quantity of steam will escape, a proportionate quantity of heat will be absorbed from the water, and will become concealed in the steam, and the temperature of the water will immediately fall to 212°; because all the heat above this quantity was absorbed by just as much water as it could convert into steam.

But in making this experiment, if the quantity of water contained in the close vessel or boiler do not exceed one fourth of the whole volume of the vessel, the results will be very different. In this case a temperature of about 680° will convert the whole of the water into steam: for, notwithstanding the great pressure which exists in the vessel, and which opposes the formation of steam, the tendency of that high temperature to produce the elastic state is adequate to overcome the opposition of the pressure. Intermediate ratios of water, compared with the volume of the containing vessel, will afford corresponding ratios of steam, compared with the unchanged residual volume of water. The same holds good with other liquids, except that the space occupied by the vapour, and the temperature necessary for its formation, so as to overcome the pressure, will be different for each.

Thus, when water is exposed, under ordinary circumstances, to a sufficient heat, it is the easy escape of the steam that prevents the heating of the water beyond 212°; but when the steam is confined, the temperature may be elevated above that point in proportion to the force which confines it; from this elevation, however, it immediately descends again to 212°, as soon as the steam is at liberty to form, the quantity of heat which occasioned the increase of temperature being thus removed. It should here be observed, that 212° is the boiling point of water only when the barometer stands at 30 inches: at 31, the boiling point is 213·76: at 29, it is but 210·19: in a common vacuum, it is 70°.

It is now of importance that we should take a survey of the two processes which are opposed to the melting of ice and the vaporisation of water; namely, the con-

densation of steam and the freezing of water; and it will appear that the phenomena of both are precisely in accordance with the facts detailed on the converse side.

Since water at 212° absorbs a large quantity of heat, which converts it into steam, but is not sensible to the thermometer, we might expect that a given weight of steam at 212° should contain, and would communicate, much more caloric than a similar weight of water at 212°. This is, accordingly, the case: for if a pound of steam at 212° be received into 5·56 pounds of water at 32°, the former will be condensed into water; and the whole, amounting to 6·56 pounds of water, will have the temperature of 212°. The temperature of the steam (now water) has not been reduced, yet 5·56 pounds of water have been raised from 32° to 212°; that is, 180° for each pound, or 1000 (180° × 5·56) in all. Had a pound of water at 212°, instead of a pound of steam at 212°, been mixed with the 5·56 pounds of water at 32°, the resulting temperature would only have been 64° instead of 212°. Hence the number of degrees of heat which steam at 212° contains in a latent state, and which does not elevate its temperature, is 1000.

If the temperature of the water be now reduced, it will sink progressively to 32°, or the freezing point: but at this degree, it will be recollected that ice begins to melt, and in so doing absorbs and conceals a very large portion of caloric; consequently, when the water is returning back to the state of ice, we should expect to have this portion of caloric liberated and rendered sensible. Accordingly this happens; and that it does, the following facts are sufficient proofs: — In the cooling of water, it may be reduced many degrees below 32°, without freezing, provided that it be not agitated, and that it is kept perfectly still: Dr. Thomson cooled it as low as 5°. Suppose, then, that its temperature is reduced to 20° without freezing. If we communicate a tremulous motion to the water, a great portion will be suddenly converted into ice; the

quantity will, according to Thomson, be proportionate to the previous coldness. During the freezing, the caloric of fluidity will be liberated in such quantity as will raise the whole temperature to 32°; a clear proof that the concealed caloric of the water was extricated and rendered sensible so as to raise the thermometer 12°. Similar phenomena have been observed in the solidification of other substances which remained fused at the temperature at which they naturally become concrete. Mr. Keir states*, that sulphuric acid, when of sp. gr. 1·78, the density at which it most readily freezes, may be cooled to 29° without doing so. Agitation then makes it suddenly freeze, and the temperature instantly rises to 45°, its freezing point.

That water in the process of freezing parts with a quantity of heat, which had been latent in it, is proved by the fact that, in order to be reconverted into water, solid ice must receive a large supply of heat from some external source. If this quantity of heat derived from an external source must be combined with the ice in order to convert it into water, it is very obvious that, in the contrary process, the water must part with the same quantity of heat in order to be restored to the solid state. The heat parted with by the water is not sensible in the ice, because the temperature of the latter is not higher than that of the former: it is not latent in the ice, because, if it were, the ice would contain sufficient latent heat to liquefy it, without the necessity of deriving a supply from any external source, which is contrary to established fact.

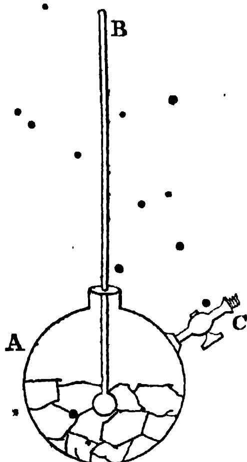
It is owing to the large quantity of latent heat given out in the process of solidification, that a considerable period of time is occupied in the congelation of a mass of water exposed to an atmosphere below 32°. The process commences by small portions of the water shooting into crystals of ice. These dismiss their latent heat, which becomes for the moment sensible in the surrounding water, and still keeps it in the liquid state.

* Philosophical Transactions, 1787.

The water, however, presently imparts this heat to the air; and the temperature being again lowered, new crystals of ice are produced, and heat again developed: and this process continues until the water is completely solidified.

It may be proved in the most direct manner, that while water is undergoing the process of congelation, and is maintained at the fixed temperature of 32°, it constantly dismisses heat; which is received by the surrounding air, and becomes sensible in it. Let a highly sensible air thermometer be placed over a vessel containing water exposed to an atmosphere below 32°: while the process of congelation is going on, the thermometer will be continually affected by a current of air proceeding from the water upwards, and it will indicate a higher temperature than the temperature of the surrounding air. It appears, therefore, that the water in the process of congelation imparts to the air immediately above it the caloric of fluidity which it dismisses; and that the air, thus becoming lighter than the surrounding air, ascends.

From all that has been said, it is now manifest, that when ice melts caloric is absorbed, which does not affect its temperature; and, conversely, when water becomes ice, caloric is liberated, and becomes sensible in the surrounding air. When water becomes steam, caloric is similarly absorbed, and does not affect the temperature; and when steam becomes water, its concealed heat is extricated.



The annexed figure represents a simple apparatus adapted for experiments of the most impressive character. It must

be made altogether air-tight. A is a sphere of copper containing coarsely powdered ice. B is a thermometer, with its scale engraved on the stem; its bulb is immersed in the ice: it is fastened into the neck of the sphere by means of a perforated air-tight cork. C is a stop-cock communicating with the interior. Suppose that, at the commencement of the experiment, the mercury of the thermometer immersed in the ice stands at 10°. The heat of a lamp being applied, the temperature of the ice rises gradually until it reaches 32°, and then the thermometer ceases to rise higher. Meanwhile, the ice begins to melt, and, after some time, it is all converted into water. As soon as this happens, and not until then, the thermometer again begins to rise: it continues to do so until it reaches 212°, and then it stands still again, provided that the stop-cock C is open. For now, the heat entering at the bottom, passes into the water, and joins or combines with some so as to form steam. The steam is formed in bubbles, like those of air, at the bottom of the vessel, and, rising to the surface, issues with force through the stop-cock: nor can any application of heat beneath raise the thermometer higher, so long as the steam can freely pass off. Let the stop-cock be now shut: the thermometer will instantly begin to rise; for the heat that previously passed off in the steam, can no longer do so; it must, therefore, remain in its sensible form in the water, and the temperature would continue to rise, if the heat beneath were sufficient, until the whole apparatus would burst in pieces with the force of a bomb. But it is not safe to let the thermometer rise more than as many degrees as will prove the fact. When the thermometer indicates that the temperature of the water is 232°, let the stop-cock be opened: there will be an instantaneous gush of steam, and the water will, in a moment, be reduced to the temperature of 212°; the excess of heat now finding a sudden vent through the medium of the steam.

The relation between caloric and the three forms of water may be considered a type illustrative of the re-

lations between caloric and all other matter, as far as the subject has been examined. All bodies, in changing their state, render heat either latent or sensible. If a solid becomes a fluid or a gas, or if a fluid becomes a gas, caloric is absorbed and rendered latent; and if a gas becomes a fluid or a solid, or if a fluid becomes solid, caloric is liberated, and becomes sensible. In many cases, where caloric is absorbed, and an abundant supply can be obtained, the loss of it is not readily perceived: this is the case when water is converted into steam by artificial heat. But where free caloric cannot be abundantly supplied, heat is abstracted from all the surrounding objects, even though they are at the ordinary temperature of the air; and they are rendered cold, because the quantity of heat necessary to supply the portion absorbed during the change of state cannot be replaced with as much celerity as the absorption took place. This will explain the operation of freezing mixtures.

In concluding this part of the subject, it may be necessary to revert to some facts already described. It has been stated, that water constitutes an exception to the general law; as it does not contract from $39\frac{1}{2}°$ downwards to $32°$, but, on the contrary, expands. Several solutions are similarly circumstanced. These exceptions, however, may be but apparent, and may be explained with reference to the single instance of water. When a liquid is about to crystallise, it begins to expand; and the expansion is supposed to be attributable to an effort of the constituent particles of the crystal to attach themselves one to another, according to a kind of polar arrangement, similar to that which takes place in magnetic and electric attractions. It is to this effort which probably, causes the particles to separate a little, and expansion to result. When water is cooled to $39\frac{1}{2}°$, and becomes specifically lighter, it may be owing to this cause; and, without this, it perhaps would not be an exception.

It has been shown that all bodies in the ordinary state contain a quantity of caloric which does not affect the organs of sensation, or the thermometer, like free or sen-

sible heat, until some change is effected on the condition of the body, which liberates a part of its caloric, and calls it into action. If a bar of iron, in this ordinary state, be cut into several lengths, each will take with it its proper proportion of caloric. From this it is plain that any two or more pieces of iron of the same quality, quantity, and temperature, no matter whether they had ever formed one piece or not, will contain the same quantity of heat: and the same may be said of other metals, and of stones, woods, or any thing else. If all the other qualities of the body be alike, so also must be that one of containing caloric. Further, it is an obvious truth, that if two pieces of iron, the same in every respect, be exposed to heat or cold—as, for instance, that of boiling or freezing water, by immersion in it—they will both become equally hot or cold, as they will absorb or part with the same quantity of caloric.

But if we take a piece of iron, and an equal weight of a different metal, suppose copper, and expose them to the same temperature, as by immersion in boiling water, they will both arrive, eventually, at the same degree of heat; but they will have absorbed very different quantities of it in order to do so. The same observation, generally, may be applied to all the bodies in nature, whether solids, fluids, or gases.

Now, as bodies, in order to be brought to the same degree of heat, whether the highest or the lowest, will require different quantities of caloric, the inference is, that different bodies, at every degree of temperature, whether natural or artificial, must always contain different quantities of heat, the bulks or weights being alike. Thus, the quantity of heat that would raise one kind or state of matter 10°, would raise another but 8°. Or, to explain the matter more generally, it appears that different bodies are so constructed by nature, that they require different quantities of heat to raise them to the same temperature. And if equal quantities of heat be made to enter different bodies, they will raise the bodies to different temperatures. This quality

of matter is called the *capacity* of bodies for heat; and the quantity of heat that is thus required for any particular body, to raise it to a certain temperature, is called its *specific* caloric.

The same kind of matter, while in the same state, has always the same capacity for caloric*: at least, this is true within a moderate range of temperature. Suppose the body to be water, and that we take a pound at 60°, and a pound at 212°, that is, boiling: each of these pounds contains a different quantity of caloric. When mixed, the effect ought to be, that, as the capacity of each pound of water for caloric is the same, and as the hotter must give to the colder as much as will bring both to the same heat, that degree ought to be midway between the two heats, and may be found by adding 60 to 212, the sum of which, 272, being equally divided, gives 136° as the arithmetical mean, and should be the resulting temperature. That 136° will be the resulting temperature, any one may convince himself, by immersing a thermometer into a mixture of equal weights of boiling water and of water at 60°.

Here, therefore, there is no heat lost or unaccounted for: whatever the hot water lost, the cold water is proved to have gained. But when different bodies are concerned, which, as already observed, have different capacities for caloric, the case is altered. For instance, if a pound of water at 60° be mixed with a pound of mercury at 212°, the arithmetical mean in this case, as in the last, is 136°. But, after shaking both of these liquids well, so as to produce uniformity of temperature,

* This position, which was supported by Irvine, Crawford, and Wilcke, has been called in question by Dulong and Petit. They affirm, as the result of experiment, that the specific heat of bodies increases with their temperature. Experiments indicating differences which, in so delicate a subject, may be considered trivial, being sometimes so small as 0·002 between the specific heats of a body at two different temperatures, do not seem to afford sufficiently strong evidence for the establishment of one opinion and the controversion of another. Still it may be well founded: the fact, that boiling and cold water produce the arithmetical mean, only shows that the specific heat of water does not increase with its temperature within the range of 32° to 212°. But the fact that the expansion of liquids by heat is not equable throughout the whole scale, would appear to favour the idea that their capacities also vary.

we find that the resulting heat, instead of being the arithmetical mean, is but 64·9°, or 171° lower: hence, this quantity of caloric remains unaccounted for.

The experiment evinces that the pound of mercury was reduced from 212° to 64·9°: hence it lost 147·1°, which, being communicated to the water, raised it only 4·9°: and, therefore, the quantity of heat which raises a given weight of mercury 147·1°, would raise the same weight of water but 4·9°, or one thirtieth. Thus, the heat that would raise water 1°, would raise mercury 30°: water has, therefore, a capacity of containing heat 30 times greater than mercury, without having its temperature more elevated than that of the mercury. Or the same fact is otherwise expressed, by saying that the specific heat of mercury is 30 times greater than that of water. If the specific heat of water be represented by unity or 1, that of the mercury will be ($\frac{1}{30}$ =) 0·033. It may be admitted as a general truth, with very few exceptions, that all bodies require different quantities of heat to bring them to the same temperature; or, in other words, that almost every kind of matter contains a quantity of heat peculiar to itself.

Such are the chief facts which have been ascertained with regard to the absorption of heat by bodies, and its existence either in a concealed state, without raising their temperature, or doing so in a less degree than it would other kinds of matter. Hitherto the explanations given have been confined to a simple expression of facts, for in these there can be no mistake; and the language of speculation has been avoided. It is now necessary to give some account of the two theories which have been most relied on for the explanation of these phenomena: I shall begin with Dr. Black's doctrine of latent heat.

When Dr. Black commenced his lectures, in the university of Glasgow, in 1757, the general opinion regarding fluidity was, that it is produced by a *small* addition to the quantity of heat which a body contains when once raised to the point at which it is ready to melt; that its return to the solid state depends on a very small

diminution of heat after it has cooled to the melting point; that a solid, when changed into a fluid, receives no greater addition to its heat than what is indicated after fusion by the thermometer; and that when the fluid body is again made to congeal, it suffers no greater loss of heat than the thermometer indicates. But the truth is, that when ice or any solid is melting, it receives a much greater quantity of heat than what is immediately after perceptible: and this great quantity *must* be received, because it is the *cause* of the fluidity induced. When the melted ice or other body is again about to become solid, it cannot do so without parting with the heat which caused the fluidity, and which had been concealed or *latent*.

Previously to the time of Dr. Black, it was in the same manner supposed, that when once water, or any liquid, exposed to heat, has risen to its boiling point, nothing more is necessary than the addition of a *little* more heat to change it into vapour. And when the vapour of water has cooled so far as to be ready for condensation, it was thought that the return into the state of water will happen at once, after losing a very small quantity of heat only. But Dr. Black proved that in the vaporisation of water a vast quantity of heat enters it, which afterwards is extricated during the condensation of the vapour into water. The quantity of latent heat contained in steam he estimated by distilling 3 measures of water into a worm immersed in 38 measures of water at 52°: the 38 measures were heated 71° higher. Hence, 3 measures in steam heated 38 measures (that is, 12$\frac{2}{3}$ times as much) 71° higher: the total quantity of latent heat in the steam is, therefore, found by multiplying 71° by 12$\frac{2}{3}$: the product is 899$\frac{1}{3}$°.* But the original three measures of water were at 52°, and they were raised to vapour of 212°: therefore 160° (difference of 52° and 242°), the sensible heat of the steam, must be subtracted from 899$\frac{1}{3}$°; and the remainder, 739°, is the latent heat of the vapour; or, making allowances for dispersion and loss of heat, Dr. Black estimated the

latent heat at 744°,—a number which Mr. Watt afterwards changed to 900° or 950°. Lavoisier estimates it at 1000°; and this is generally adopted.

Dr. Black considered heat to be a substance of a distinct and peculiar nature, "susceptible of union or combination with bodies, similar to those combinations which the chemist observes between numberless varieties of substance:" and he conceived that, in cases of both expansion and fluidity, a combination with heat takes place, but of a different kind in each. Heat enters into vapour and into melting ice in the same way; it combines; does not heat; but merely constitutes the vaporific and liquid form. In fine, Dr. Black conceived it a point fully established, that when a fluid is raised to its boiling point by the copious application of heat, its particles suddenly combine with a great quantity of heat; and their mutual relation is thus so far changed, that they no longer attract each other, and form drops of liquid, but avoid each other, and separate to a vast distance, and would separate much further, but for the pressure of the atmosphere.*

Dr. Irvine was the pupil of Dr. Black, and his successor to the chemical chair of Glasgow. He took altogether a different view of the cause of the disappearance of heat in liquefaction and vaporisation. He supposed that the absorption of heat into the latent state is not the cause of liquefaction and vaporisation, but the effect; and he attributed the absorption to what is called change of capacity for heat, or that quality of matter which causes one kind to be more or less heated than another by the addition of the same quantity of heat. This unequal effect of equal increments of heat was distinguished by Black and Irvine, about the same time, by the term *capacity*. The 140°, that disappear when ice is melted, was called by Black *latent heat*: he asserted it to be the cause of fusion, to combine chemically with the solid, and to form a substance different from both,—a liquid. This opinion was considered by Irvine

* Black's Lectures, i. 175.

as not sufficiently comprehensive: he did not allow the entrance of latent heat into bodies as happening upon different principles from those which always direct the operations of heat upon matter; he imagined that latent heat is only a case of what occurs in any affection of bodies by heat, and that the caloric exists there precisely in the same way as at other times. He thought that something more happens in fusion than Black imagined; that the capacity of water for heat might be found to exceed that of ice, as afterwards he proved experimentally; and that a new reason might be assigned, why ice, while melting, refuses to admit an augmentation of temperature. The reason is, that it is then changing its capacity: from a substance easily heated, it becomes one that is heated with difficulty. All fluid bodies are heated with more difficulty than when solid; not because fluids transmit heat more slowly, for this is the contrary of the fact; but because the same quantity of caloric will heat a solid a greater number of degrees than it will a fluid. Capacity is no more than the expression of the rise or fall of temperature produced by equal quantities of caloric upon different bodies. He concluded, as a general law, that the capacity of all solids for heat is increased by fusion, and that of all fluids by vaporisation. It appears, then, that beside Black's discovery of the great quantity of caloric necessary for converting solids into fluids, another remarkable alteration is produced in the habits of the body with regard to heat: from requiring but a small quantity to raise its temperature a certain number of degrees, it has become a body requiring a great quantity to produce that effect; therefore, in fusion, the fluid formed must, on account of this change of capacity, require a supply of caloric to enable it to remain even at the same temperature with the surrounding bodies. It is clear, that if a solid be converted into a fluid of an increased capacity, it must absorb heat, which will exhibit the same phenomena as latent heat; and the same applies to the conversion of a fluid to the aëriform state. This explanation is not opposed, but supplemental, to

Black's doctrine. Both theories admit the entrance of a large quantity of caloric during fusion: Irvine's only differs in offering an explanation of the enlargement of the specific heat of the fused body, and in denying any peculiar or unusual combination of caloric.*

In commenting on this doctrine, Dr. Black replies to the following effect: — "Dr. Irvine imagines that it is not necessary to suppose a special combination of matter to take place with caloric, which, while thus combined, is called latent heat. The explanation, it is said, may be as well derived from the fact, that a body while in its fluid state has a greater capacity for heat; that it absorbs more heat in order to rise one degree than when in the solid form. Thus, ice is said to have less capacity than water: when ice melts, a quantity of heat must, therefore, enter the water produced, without making it warmer; and when water freezes, heat must leave the freezing water, without leaving it colder. The absorption of heat into the melting ice is, therefore, not the cause, but the consequence, of its liquefaction; while the extrication of latent heat from freezing water is not the cause, but the consequence, of becoming solid. Here, then, the change from solidity to fluidity is not accounted for, although it is the chief phenomenon. Fluidity is not attributable to cessation of cohesion; for how, then, would it be restored? and we know that cohesive attraction does still act in fluids. If it be maintained, that sensible heat increases or diminishes the distance of the particles, and thus acts on cohesion, why is not this an invariable effect? and how happens it that water may be cooled to 24°, without being acted on by cohesive attraction, and being converted into a solid? By agitating such overcooled liquids, heat is liberated which before was latent, and a part of the liquid solidifies: this latent heat was the cause of its protracted fluidity."

To this Dr. Irvine seems not to have been able to furnish an adequate reply. He says the theory of capacities asserts that the caloric rushes into the ice, en-

* Irvine's Essays, Part I. Essay I.

larging and satisfying its capacity at the same instant, and by the same action: the fusion, the increase of capacity, and the heating of the body, according to the new capacity, are simultaneous — the work of the same moment. It may be difficult, he says, to explain how this happens on this hypothesis, but not more so than on any other. On the other hand, the permanent increase of the capacity of all solids when melted, and of all fluids (as he affirms) when vaporised, — sufficiently striking facts, — are not explained by Black's theory; while, on the opposite hypothesis (he conceives), the phenomena are readily accounted for. It may be supposed either that the increased capacity and the fluidity are the co-existent consequences of some common cause, or that the union of the latent caloric and the solid is accompanied, at the moment of its taking place, with a new capacity for heat, in proportion to which the latent caloric is great or small.

It now only remains to explain a few of the chief phenomena according to each of these theories, in order that their merits may the more readily be contrasted: for it is in the language of one or the other that all facts relative to heat are expressed by chemists. In explaining these phenomena, we need only attend to the cases in which the change from solidity to liquidity or the gaseous state causes absorption and disappearance of heat; those in which it is rendered sensible being only their converse.

In such instances, the followers of Black would say that the absorbed heat becomes latent, has chemically combined with the solid or liquid, and is the cause of the liquidity or of the gaseous state. Dr. Irvine would suppose that during the change of state there is a change of capacity, the new state requiring more caloric to maintain it at the original temperature; hence, an absorption of heat must take place to supply the increased capacity, and this absorption is an *effect* of liquefaction and vaporisation, and not the cause. It is not only in case of transition from one distinct state to another, that a change

in the quantity of caloric takes place; but it happens in some of the modifications of each state: thus, when a change of density happens, as if a piece of iron be violently struck, its specific gravity is increased; it has become brittle, and very hot. If it be again struck, a little more heat and condensation may be produced; but after this, no effect results from striking it, either with regard to condensation or heat, until its original density and condition be restored by heating the iron red-hot in the fire: this process also restores its malleability. The same happens with several other metals, but not with all to the extent described. When the density of a liquid is increased by dissolving some other substance in it; and, universally, when any two liquids combine chemically; there is an extrication of heat, sometimes considerable. The mixture of oil of vitriol and water affords a good example of this heat; and if the specific gravity of a gas or vapour be increased, there will be an increase of its temperature. This is so great in condensing air in the barrel of a very small syringe, close at one end, that, as already mentioned, a bit of agaric contained in it is thus set on fire. The converse of all these propositions is, no doubt, equally true; but it is only in the case of gases or vapours that it is very distinctly observable. If the density of a gas or vapour be lessened, cold is produced, as appears from the sinking of a thermometer in the receiver of an air-pump when the air is rarified; because heat is absorbed from all the surrounding media. All these cases of change of density, in which heat is rendered sensible, would be explained, by the followers of Black, by declaring that some of the heat necessary to the existence of the body as a solid, liquid, or gas, was forced out of it by the approximation of its particles; and as the particles of solids and liquids are preserved *in equilibrio*, by the balance of cohesive attraction and calorific repulsion, any cause that disturbs this balance must change the relation of the body with respect to heat. It does not seem to me that Dr. Black followed up this part of the subject with sufficient attention. According to the

theory of Irvine, the extrication of heat, in all such cases, depends on a change of capacity for heat in the body concerned; the effect of which is, that when increase of density happens, diminution of capacity takes place, and less heat is necessary to maintain the body at the original temperature than before; because, in the new degree of density and capacity, smaller additions of heat than before will suffice for the production of any given temperature: hence, heat is extricated.

Both theories agree in representing that gases contain more caloric than liquids, and liquids than solids; yet this greater quantity of caloric is not sensible, or in a state of freedom, but inactive and concealed; so that, to the thermometer, a solid, a liquid, and a gas, all appear to contain the same quantity of heat. The condition of heat that is discoverable by the thermometer, or by the organs of sensation, is called *temperature*.

We have seen that the chief feature of Irvine's theory is its representing liquefaction and vaporisation as being caused by increase of capacity. About eighteen years since, in an essay which obtained the prize of the French Institute, MM. Delaroche and Bérard showed that the specific heat of vapour of water is but 0·847, while that of water itself is 1·000. This would prove that the capacity of vapour is *less*, instead of greater, than that of water: and if so, vaporisation cannot depend on the cause assigned by Irvine. But these philosophers acknowledge that, "though we consider our determination of the specific heat of vapour as not far from the truth, we have not such entire confidence in it as to draw from it a conclusion of such importance." But, for the subversion of Irvine's theory, they seem to rely on an experiment which gave the specific heat of water as 1·000, while, by calculation, it should be but 0·633; or, giving the utmost latitude for error, 0·800. It is necessary, therefore, they conceive, to abandon the hypothesis which ascribes the evolution of heat during combination (viz. the combination of the two elements of water) to a diminution of the specific heat in the bodies combined,

and to admit, with Black, the existence of latent caloric in bodies.

Modern discovery has accumulated a number of facts which do not seem to be explicable by the theory of Irvine. In the chapter on combustion, several solids and liquids will be mentioned, which, when heated gently, or even touched, explode with violence and produce gaseous products. Here, then, are numerous instances of the conversion of solids and liquids into gases, accompanied by the copious evolution of heat.—What is its source? If, in the production of the gas, there be an increase of capacity for heat, whence comes the free caloric that appears? Why should we not rather expect cold to result, when gunpowder is transformed into a vast volume of gas? For the answer to these questions, we must apply to the doctrine of latent heat. MM. Dulong and Petit give the following as a consequence deducible from their researches, the details of which, however, they have not stated: — "The quantity of heat developed at the instant of the combination of bodies, has no relation to the capacity of the elements: in the greater number of cases, this loss of heat is not followed by any diminution in the capacity of the compounds formed."

We have now to direct our attention to the heating and cooling of bodies, and the processes by which these changes are effected. If a hot mass of metal be laid on one that is cold, the former loses heat, and what it loses the other acquires: both are now hot; and it is to be enquired, Why did this partition occur? It has been already observed, that, according to the corpuscular hypothesis of caloric, its particles are self-repellent; and the more so, the nearer they are to each other. The consequence of which must be, that when the particles have liberty of motion, they will constantly endeavour to diffuse themselves. If a great number be accumulated in one place, they will immediately, if not restrained, begin to separate in all directions, until the accumulation is removed: they are then at rest, and in a state called the *equilibrium* of caloric; which merely means, that the

surrounding objects contain as much caloric as attaches itself to them, so as to saturate their capacity, and equalise their temperatures. This diffusion of caloric in bodies does not depend exclusively on a repulsive agency, but is assisted, in all probability, by an attractive force; for if caloric be matter, its particles should attract and be attracted by other matter with different degrees of energy: but on this part of the subject more will be said hereafter.

The facility with which heat enters or leaves bodies depends much on the nature of the body; some species permitting the passage of caloric through them with ease, and others with much difficulty. This property is called the capability of bodies to *conduct* heat. Instances of its existence occur constantly in our common experience; thus, when there is occasion to hold any hot metallic instrument, we take care that the part by which it is to be held shall not be made of metal, but of wood; for the metal would allow the caloric to pass in so condensed a state, and with such rapidity, into the hand, as to prove painful, whereas wood, and such other substances, will not permit it to pass otherwise than slowly. Hence the sensation produced by one portion of caloric on the hand has ceased before that of another commences, and there can be no accumulation. Metal is, therefore, called a good *conductor* of heat, and wood a bad one; and bodies have very different powers in this respect. Thus, water, heated to 150°, is capable of scalding: but air, heated to 260°*, can be endured without any painful sensation; because water can much more perfectly be brought in contact with the body, than so rare a substance as air. The conducting power of air saturated with moisture is to that of air commonly dry as 230 to $80\frac{2}{3}$; hence the former feels so much colder to the human body.†

In consequence of this property which bodies possess, of conducting heat with more or less facility, certain deceptive results follow, which it will be necessary

* Blagden, Philosoph. Trans. 1775. † Rumford, ibid. 1786.

to explain. If a piece of cork, and an equal bulk of metal, be kept for a length of time in boiling water, then withdrawn and hastily dried, the metal will feel intolerably hot to the hand, while the cork feels little more than warm. Here it might be supposed that the two bodies, although both exposed to the heat of boiling water, had been heated to different temperatures, whereas a thermometer applied to each will stand at the same height; proving that the different effect on the organs of sensation are owing to the rapid transmission of caloric to the hand in one instance, and to its slow communication in the other. It is a fact attributable to the same cause, that if a piece of metal and a piece of cork, both at the common temperature of the air, be applied to one's skin, the metal will feel cold, and the cork comparatively warm, because heat is withdrawn from the skin more rapidly by the former than by the latter.

Such bodies as are of greatest specific gravity are, generally speaking, the best conductors of heat; but the observation is not universally true. If a body, which is of great specific gravity, and is a good conductor of heat, have its specific gravity lessened, so will also be its conducting power. Thus, metals are all good conductors of heat; yet their filings, which are specifically lighter, in consequence of the spaces between their particles, are very inferior in conducting power; and whatever conducting power wood may have, it is much lessened by being converted into sawdust.

Good conductors of heat would evidently form bad clothing. The object of clothing is to intercept the heat, and preserve the body as much as possible at a uniform temperature. In cold weather, the temperature of the atmosphere being lower than that of the body, clothing formed of non-conductors prevents the too rapid escape of heat from the body to the surrounding air; and, in very hot weather, it answers a contrary purpose,— preventing the too rapid communication of heat to the body. Animals are clothed in fur, wool, feathers, &c.—all non-conductors; and man borrows his clothing, in a great degree, from them.

All that has been said on the subject of the conducting power of bodies refers to such as are in the solid state; for those that are fluid are all very bad conductors of heat. This has been experimentally proved by applying heat (that, for instance, arising from a stratum of burning ether) to the surface of the liquid filling a tall cylindrical vessel; and having the bulb of a thermometer placed some distance below the source of heat. The rise of the thermometer is extremely slow. It had been even doubted that this small rise of temperature was attributable to the heat conducted by the fluid; it was supposed that the heat had been conveyed down by the matter composing the sides of the cylinder, until the question was set at rest by an experiment of the late Dr. Murray, of Edinburgh. He constructed a cylindrical vessel of ice; filled it with oil at 32°; fixed a thermometer at some distance below the surface; and applied heat to the surface. The thermometer rose 5½° in 7 minutes, clearly showing that, although slowly, the oil did conduct the heat, inasmuch as ice can neither conduct nor receive heat higher than 32°; — any additional heat melts it, and becomes latent. Liquids, like solids, seem to conduct better in proportion as they are more dense: — thus, spirit of wine, a very light fluid, is a bad conductor; oil is heavier, and conducts better; proof spirit is heavier, and is a better conductor; water is still heavier, and is a still better conductor; and quicksilver, the heaviest of all liquids, is, comparatively, an excellent conductor of heat.

As liquids are bad conductors, it may be asked how it happens that they become so speedily hot, and so soon boil when they are exposed to the action of fire. In order to understand this, we must revert to a fact already explained, that when a liquid is heated, it becomes specifically lighter. When a vessel containing water is laid on the fire, the layer of water at the bottom, and next the fire, first becomes hot; it also becomes specifically lighter, and consequently rises through the water

in the same manner as a cork or any other light body would rise. This portion of heated water having been thus removed by its lightness, the next layer, now in contact with the bottom, or source of heat, becomes heated in its turn, and ascends; and so on, layer after layer is heated, and ascends until the water boils.

These ascending currents, along with the imperfect conducting power of liquids, assign the reason that they receive downward transmissions of heat so slowly. As soon as a layer of water at some depth from the surface receives a portion of caloric, instead of transmitting it to the layer next beneath, it ascends to the top.

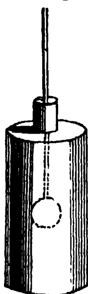
Although it is the kind of matter that regulates the difficulty or facility with which caloric passes through it, yet, with regard to receiving caloric in the first instance, or parting with it afterwards, the conducting power is by no means the only one concerned; these effects depend in a great measure on the surface which receives or transmits. Thus, if two similar pieces of the same metal, polished alike, be heated equally, and set to cool at the same moment, in the same medium, they will be reduced to the ordinary temperature of the air in the same space of time. But if one of the metals have its polish impaired by scratching with sand-paper, and if they be now equally heated, and set to cool as before, the scratched piece of metal will part with its heat much sooner than the polished one; and however difficult it may be to conceive how the polish can act in retaining the heat, it is certain that the fact is so.

When a body, such as the piece of metal just now instanced, is heated, and left in the open air to cool spontaneously, the heat gradually flies off from it on all sides, in the form of radii, or rays; and from this circumstance the departure of heat from the body is called the *radiation of caloric*.

Some bodies have a greater power of radiating heat than others: the consequence of which is, that those bodies which have the greatest radiating power will cool in the shortest time; and by this rapidity of cooling, the

radiating power may be estimated, and rendered manifest by experiment.

Let two cylindrical vessels of tin-plate be prepared, similar to the one represented in the margin, capable of holding about half a pint each. Each must have a cork fitted to its mouth, through which a thermometer tube passes, the bulb standing about the middle of the vessel. Let one of these cylinders be painted over with lamp-black mixed with water and a little size. If both vessels be filled with boiling water exactly at the same time, the corks and thermometers being immediately introduced, it will be found that the thermometer of the blackened vessel sinks very rapidly, while that of the bright one falls very slowly. The experiment proves that the surface of lamp-black radiated heat more rapidly than that of bright metal. Indeed, the experiment may be made with the thermometers only, one having its bulb blackened with lamp-black, and the other being clean. If both be raised to the same temperature before a fire, and then allowed to cool, the mercury in the blackened one will sink at a much quicker rate.

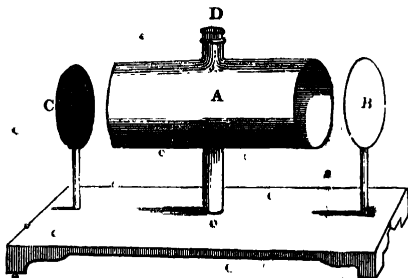


The coating used in both experiments was lamp-black, for this substance is found to be the best radiator. If its radiating power be estimated at 100, then that of glass would be found to be 90, bright lead 19, and tin-plate only 12; and although bright lead radiates with a power of but 19, if the lead be a little tarnished, its power is raised so high as 45.

In general, it may be affirmed that all substances in nature have different radiating powers. In the case of metals, the radiation depends on the mere surface, without reference to the substratum: but in the case of other radiating substances, the thickness of the coating constituting the surface, within moderate limits, increases the radiation. The radiation of heat takes place more

rapidly in a vacuum than in the air. It takes place in all gases.

Whatever the cause may be that enables those surfaces to radiate caloric with such facility, and transmit it in right lines, it is but natural to suppose that a surface of the same kind would also permit the entrance of caloric. Accordingly, we find that the fact is so; and that the surfaces of bodies which radiate caloric with facility, also absorb it with facility; and, conversely, that surfaces which do not radiate caloric with much energy, are also those which will not readily absorb it when radiated from other bodies. For instance, polished metals, which radiate caloric imperfectly, receive it imperfectly when radiated from other bodies; but when their surface has its radiating power increased by being scratched by sand-paper, or tarnished, it then absorbs better. And lamp-black, which is the best of all radiators, is also the best of all absorbers. The following apparatus exemplifies this position:—A tin-plate cylinder, A, is



placed horizontally, and opposite its ends are placed tin-plate discs, one of which is to be bright at both surfaces, and the other is to be painted with lamp-black and sized water on the surface next the cylinder. Let duplicate discs of tin-plate be provided: let one of these be stuck to the disc B by means of a thin stratum of lard interposed; and the other similarly cemented to the disc C, which has the blackened surface, that surface being

next to the cylinder. Each pair of discs should be 2 inches distant from the opposite end of the cylinder. Let the cylinder be filled with boiling water through the mouth D, and corked. The heat now radiates from both ends of the cylinder; each contiguous disc absorbs the radiated heat: but the blackened disc will soon evince that it has absorbed with more avidity, for it will become so warm that the lard will melt, and the disc which had been in contact with it will fall off; while the pair of discs at the other end will remain a long time unaffected, and perhaps may not separate. If both ends of the cylinder are blackened, the result will be more decisive, because more heat will be radiated from the cylinder.

A question here occurs: — Does this fact depend on any known property of the metal? and are there any considerations which might have led us to an anticipation of the result? It might naturally be supposed, that a surface found to radiate heat with such facility, and to receive it so readily when radiated from other bodies, should easily allow a passage through the material of which it is composed; and that, on this account, the best conductors of heat would also be the best radiators. But so far is this inference from being correct, that there is reason to believe the reverse to be true; for metals, which are the best conductors of caloric, are its worst radiators, that is, while they are bright and untarnished: and, in a great many cases, the best radiators, as lamp-black, linen, paper, &c., are very bad conductors of caloric. It being the fact, that good conductors are bad radiators, it should also be true, and it is the case, that good conductors present bad receiving surfaces; and this precisely corresponds with the experiment last described, in which the bright metal did not receive the radiated heat from the vessel of boiling water.

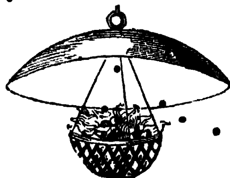
As the polished metal was proved to be a bad receiver of radiated heat, and, in fact, refused to absorb the caloric which must have radiated towards it from the cylinder of boiling water, it may be asked, what became

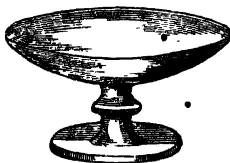
of that caloric which was refused admittance by the polished tin: it did not pass through the tin, and, therefore, it must have passed off in some other direction without entering.

It is easy to prove that caloric, under such circumstances, is reflected; and it is possible to prevent its dispersion, by collecting and concentrating it into one point. All that need be done to render its effects manifest, is, to convert the plane reflecting surface into one of a concave form; for, in this particular, caloric resembles, and is regulated by the same laws as light. If, therefore, a quantity of radiant caloric be allowed to impinge upon a concave metallic mirror, the rays will be reflected from the surface to a focus in which all the caloric will be concentrated.

To perform this experiment with advantage, an arrangement different from that just described must be made. It must be so contrived that the body, which is the source of heat, shall be at a much greater distance, and that the direct rays emanating from it shall exert little or no heating agency until they are concentrated by the reflector. To produce the effect in a striking manner, the heat made use of should be much greater than that of boiling water; burning fuel will afford the necessary temperature. One concave elliptical metallic speculum, with the heated body and the object to be heated in the conjugate foci, would answer the purpose, except that the proximity of the heated body might cause the effects of radiation and reflexion to be confounded. In order to transmit the heat to so great a distance as is necessary for distinctness, and to concentrate it afterwards, two parabolic reflectors must be made use of. The first receives caloric from the heated body, and reflects it to the second, which then collects and concentrates it in such a manner as even to set fire to a combustible placed in its focus. The mirrors may be formed of tin-plate, and the seams caused by the joining of the plates may be so nicely executed as not to prove very detrimental: about 2 feet diameter will suffice. One is to be sus-

pended from the ceiling of a room 12 feet in height. It is to have an iron-wire cage filled with burning charcoal placed in its focus. The other mirror may rest on the floor of the apartment. In the figure, the mirrors are represented as being close together, to save space. If





a little gunpowder laid on a bit of black paper be held in the focus of the lower mirror, it will explode, although, if held two or three feet higher up, that is, nearer the source of heat, it will not be affected. In this experiment, the heat radiates from the charcoal, and is reflected twice before it arrives at the gunpowder.

Since the two metallic surfaces reflect the heat from them, it is natural to suppose that they do not get hot, and, accordingly, we find that such is the case. But, besides this cause, there is another (or it may be the same), which prevents the heating of the reflectors: they are made of bright metal; and this, as we have already seen, is a bad radiator of heat, and therefore a bad receiver or absorber. Metals are the best reflectors of caloric, and the worst radiators; and, generally, it is found that the

reflecting power of bodies is strong in proportion as the radiating energy is weak.

The radiating power of glass is considerable, and, consequently, its reflecting power ought to be proportionately weak: this also is found to hold; and as it is a good radiator, so it must be a good absorber. In the experiment just described, had the reflectors been of glass, which thus powerfully absorbs, although it reflects badly, the heat would have been detained by the glass instead of being reflected on the gunpowder. That a glass mirror scarcely reflects heat, any one may convince himself by means of a common looking-glass placed properly before a hot fire. On the other hand, a metallic mirror, as has been already observed, reflects all the heat, and, consequently, does not become warm; "but if covered with black over a burning candle, you cannot keep it four minutes in the same situation (before a fire) without burning your fingers." *

With regard to the reflection of heat, therefore, it is plain that it is not sufficient for the reflecting surface to be hard and well polished, but it must be of such a material as is a bad radiator and absorber. In the case of the glass mirror just now alluded to, the glass presents a much more even and smooth surface than the tin, and it has even a brilliant metallic coating on the back of it; but the glass being a good radiator, it must make a bad reflector. The silvering at the back has no effect: it may be removed, and the back surface roughed by grinding, without any change in the reflecting power of the other surface.

* Scheele on Air and Fire, p. 70. He says, that a glass mirror reflects *no* heat, but retains it all. Mr. Leslie, whose labours have made us acquainted with some of the most important facts in this chapter, has, however, shown that a glass mirror is not destitute of *all* reflecting power, though its power is trifling.

CHAP. VI.

LIGHT.

Having investigated the principal phenomena of heat, so far as is necessary to the subject of the present treatise, we shall now explain a few of the leading qualities of another physical agent closely connected with it.

If heat be gradually communicated to a body,—a mass of iron, for example,—no other effects can be observed for a considerable time, except an enlargement of dimensions and an elevation of temperature. At length, however, a very remarkable change will be observed. If the process be conducted in a dark room, the metal, previously invisible, will become visible, and will not only be seen itself, but will enable surrounding objects to be seen. In fact it will emit light. The body is thus said to be in a state of ignition, or, in common language, it is red-hot.

The original sources of light are, first, the celestial bodies, the sun and fixed stars; and, secondly, terrestrial bodies, in which heat is produced in so intense a degree as to be accompanied by light, as just explained. Light, being primarily produced in this manner, is distributed, in a variety of ways, through the space which surrounds us, and is the immediate means by which all objects become visible. It passes freely through the atmosphere; it strikes upon the clouds, and is reflected from them, rendering them visible. It strikes upon all terrestrial objects, and is by them modified in a curious and complicated manner; so that, when reflected by them, it produces all the phenomena of colours. Its course, when unobstructed in passing through any space or medium of a uniform character, such as glass, water, air, or a vacuum, is in straight lines; but when it passes through spaces occupied by substances of different kinds, or in different states,—as from glass to water, or from water to

air, or from air in one state of density to air in a different state,—it is liable to be bent into a crooked or even a curved path, subject to fixed and well known, though very complicated, mathematical laws. It is not necessary, even were it possible, here to enter into any explanation or development of these phenomena. Those who desire to obtain an acquaintance with them, will find them explained in works written expressly on Optics, and are referred to the Treatise on that subject in this Cyclopædia.

Light and heat so frequently accompany one another, that it has been sometimes disputed whether they are not exhibitions of the same principle. The fact, however, that heat of the greatest intensity can exist unaccompanied by light, is unquestionable; and this alone would perhaps be sufficient to establish their diversity. But it is contended, that light cannot exist without heat, and that, therefore, heat must be regarded as a quality of light. Against this it may be stated, that the sun's light reflected by the moon, although collected and condensed into a point by the most powerful optical means, has never been found to affect the most delicate thermometer. Also, that when heat and light are produced by the combustion of common fuel, the heat will be intercepted by a plate of glass, while the light will be freely transmitted. But, perhaps, the most decisive proof that the heat in the solar rays is a principle distinct from their light, is found in the fact, that by optical means the solar beam may be decomposed into its constituent elements; and that some of these elements are invisible non-luminous rays, which affect the thermometer more powerfully, and are, therefore, more calorific, than any luminous rays.*

The chemical influence of light is conspicuous in a variety of natural and artificial processes. In vegetation, light is an indispensable agent: it is by its assistance that growing plants are enabled to decompose carbonic

* Optics, Cab. Cyc. p. 89.

acid, assimilating its basis for the purposes of nutrition. Without its influence, vegetables are deficient of their due elementary constitution: they are weakly, inodorous, and of an unwholesome colour. Dr. Black proved, that the green colouring matter of vegetables, which he found to be a highly inflammable substance, is not elaborated in plants if they grow in the dark: they are blanched. The influence of light in discharging vegetable colours is manifest in the process of the bleacher: and the rapid fading of coloured paper-hangings, silks, and cottons, when exposed to strong sun-light, is well known. Its energy as a chemical agent is still more decisively seen in the influence which it exerts in promoting combination and decomposition; and the latter effect has been made use of as a measure of its power.

A beam of solar light, admitted through a horizontal thin slit in a window, and allowed to pass through a wedge of glass called a prism, the edge of the wedge being placed parallel to the slit, is found to be separated or decomposed by the action of the glass, so as to form, when received on the screen beyond the prism, not a horizontal line of light, as would otherwise be the case, but an extensive luminous band, equal in breadth to the slit in the window, and extending from top to bottom a considerable length. Different parts of this band of light exhibit different colours; the upper end being violet, and the whole being divided into horizontal streaks of colour, descending through the tints of violet, indigo, blue, green, yellow, orange, and, lastly, red, which occupies the lowest extremity of the luminous band. Now, it is found that the light occupying certain parts of this spectrum, as it is called, is capable of exerting chemical agencies, and of promoting, in various degrees, the processes of combination and decomposition. Wollaston, Ritter, and Beckmann, by a careful examination of every part of the spectrum, discovered that beyond the least brilliant extremity, namely, a little beyond the violet ray, the maximum power resides, which determines chemical combination. The experiment had been long

before made by Scheele; but he came to the conclusion, that the greatest chemical effects are produced in the violet ray itself.* This chemical ray was first named the deoxidising ray, from a mistaken hypothesis of the nature of the chemical compound on which its agency is most manifestly exerted.

It has long been supposed that the rays in or near the violet extremity of the spectrum are attended with a certain magnetising influence. The experiments, however, which have been made to decide this question, have been so extremely contradictory in the results, that no certain conclusion can be deduced from them.†

CHAP. VII.

CONSTITUTION OF THE GLOBE.

SECTION I.

THE ATMOSPHERE.

One who contemplates surrounding objects would, in all probability, be first struck with the singular nature of the air which encompasses him. Common experience shows that the atmosphere is not a void; that it is matter which is capable of affording considerable resistance to mechanical force. The impulse on the sails of a windmill or of a ship, the blowing of a bellows, or the flying of a kite, are proofs of the materiality of air too palpable to require insisting on.‡ The materiality of air is further proved by its capability of producing and pro-

* See Optics, Cab. Cyc. p. 90. † Ibid. p. 92.
‡ Pneumatics, Cab. Cyc. p. 226.

pagating sound. In the detonation of gunpowder, that substance is converted into a quantity of gas of immense elasticity, which, being at that instant confined within the compass previously occupied by the powder, bursts out with prodigious force, and strikes the external air with violence. But, because fire is concerned, more may appear to act than mere air. A simple experiment will set this objection at rest. Let a bladder, full of air, be forcibly compressed until it burst: it is best done by a powerful stroke: the air rushes out with violence, and, striking against the external air, an explosion will be produced as loud as a pistol-shot. This fact alone would prove the materiality of air; for the bladder, if struck with a force not quite sufficient to break it, returns very little sound; it must, therefore, be the air rushing out which strikes the surrounding air with such force. Were the surrounding air removed, there would be no sound: a bell, struck in the vacuum of an air-pump, cannot be heard.

It may be observed, that the bladder will bear considerable compression without bursting: its sides may be forced together; and, in short, the contained air may be pressed into a much smaller compass. It is, therefore, an unavoidable inference, that the particles of which air is composed are brought nearer together. But, since the bladder expands as soon as the compressing force is removed, it is manifest that the particles of air resume their former distance when at liberty to do. Thus, a given quantity of air may be made to occupy more or less space, that is, may be expanded or contracted; and, when contracted, it will recover its dimensions with a force like a spring. This spring, or *elasticity*, of the air is produced by the repulsive force of caloric, which tends to separate the particles, until counteracted by some opposing force.

The elasticity of the air is a force of considerable energy. When a quantity of it is compressed, or, as it is called, condensed, into a very small compass, its effort

to recover its proper bulk is prodigious; and so great, that it will sometimes burst the strongest vessels. Hence the well known danger of forcing too much air into the ball of an air-gun: it bursts, and occasions great mischief.

All these considerations proving that air is matter, it becomes a question, Does it resemble other matter in that common property, gravitation? or, in other words, has it weight? This is a question which can be answered directly in two ways. If the air possess weight, its abstraction from a vessel ought to lessen the weight of that vessel, and its addition should increase it. Accordingly, an empty glass globe is found to be lighter than the same globe filled with air.*

Thus air, like other matter, possesses weight; and the fact leads to some important considerations. For, as the atmosphere extends to a considerable height, it must be supposed that such a weight of heavy air, pressing on that portion of the atmosphere near the surface of the earth, would exert a considerable pressure on all bodies situated at the earth's surface.

Air and gases generally partake of the fundamental property of liquids, by which they transfer pressure equally in all directions; and, as a consequence of this property, the pressure arising from their own weight acts in every direction, and, as its particles possess perfect freedom of motion at any point, the pressure depends on the weight of the column of fluid above that point.† At the surface of the earth, the air sustains the whole weight of the superincumbent atmosphere: here, therefore, the air being most pressed upon, its particles are forced nearer to each other, until their self-repulsion prevents any nearer approach; and hence the density of the air is greatest at the earth's surface; that is, a closed vessel, full of air, taken at the surface, would weigh more than the same vessel filled, at a greater height in the atmo-

* PNEUMATICS, Cab. Cyc. p. 228.

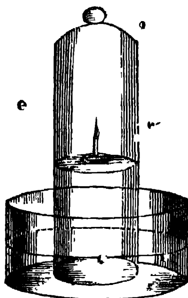
† See HYDROSTATICS, Cab. Cyc. Chaps. II. III. PNEUMATICS, Chap. IV.

sphere. The greater the height at which any given portion of air is taken, the less dense it is, because it is less compressed. The condition of being less dense is otherwise expressed by the words *more rare;* because the number of particles in a given volume is less, and, therefore, such a volume would weigh less. At length, towards the highest parts of the atmosphere, where the pressure is inconsiderable, the rarity is great; the repulsion of the particles being here an overmatch for their weight. Notwithstanding the enormous weight of the atmosphere at the surface of the earth, the destructive consequences of it are obviated by the equality of the pressure on all sides: for, to be pressed equally on all sides, obviates many of the effects of pressure as completely as not to be pressed at all.

Air is a fluid of an unalterable constitution: there is reason to believe that, but for certain processes to which it is constantly subjected, it would never suffer any change. On account of these processes, however, it is liable to great and important alterations; and these alterations are of hourly occurrence. We know, for instance, that air is injured by a number of persons breathing in it: it is thus that, in very crowded assemblies, the air becomes absolutely pernicious; and there is a dreadful instance on record, of a number of unfortunate persons whose lives were sacrificed by their being obliged to respire the same air for a length of time. In such air a candle will not burn. An equal injury, and of a similar kind, is done to air by a fire burning in it, when there is not proper ventilation: and air thus injured, if attempted to be breathed, will act as an immediate poison, and destroy life. It is worth while to enquire into the cause of this singular change.

In order to try the effect of fire, an experiment is easily made by burning a taper in a quantity of air included in a glass jar, or bell, inverted over some water, so as to prevent communication with the atmosphere. It will be found that the heat of the flame first expands

the air; but that in some time the quantity of air will perceptibly diminish, as will plainly appear by the rise of the water in the bell when it cools; at length the taper will be extinguished.



From this experiment two things are obvious: first, the air which remained in the bell after the taper had burned some time would no longer permit it to burn; and, secondly, at the end of the experiment there was less air in the bell than before; or, in other words, some of the original air was withdrawn. The question occurs, What has become of this air? An ordinary observer would answer, It is *consumed,* it is *burned:* but these explanations have no meaning; the air cannot have been annihilated; it must still exist somewhere. The answer we shall be presently able to assign.

There are many other processes beside the burning of a candle that would have diminished the quantity of air in the bell-glass. A liquid, prepared by boiling some water on a little lime and sulphur, has the property of absorbing a considerable portion of air which has been exposed to its action. The experiment is easily made by agitating some of the liquid in a bottle, well closed with a cork, and removing the cork under water: water will rush in equal in bulk to the air absorbed. We can then ascertain whether or not the air which remains is incapable of supporting flame, as it was in the experiment just now made with the candle. It will be found that it is not.

The metal called quicksilver, or, as it is otherwise called, mercury, has also the property of absorbing a certain quantity of air; but, for this purpose, it must be kept boiling in a flask filled with air for a great length of time: the portion which remains unabsorbed at the end of the process will extinguish flame, as in the former instances. But the mercury during this

operation has been very materially changed: it no longer possesses its fluidity, nor its metallic splendour; it is converted into a red scaly substance; and it is found to be heavier. Here, then, are two remarkable facts: when mercury is heated in a vessel of atmospheric air, a great quantity of the air disappears from the vessel, and the mercury increases in weight. The natural inference is, that the deficient air is contained and concealed in the mercury, and that it may be possible to detect and recover the portion thus lost. That such a recovery is practicable, appears from the following fact:— If, after the air has been absorbed by the mercury, the heat be increased to ignition, the red scaly matter into which the mercury was changed will restore every particle of air which it had absorbed, and the mercury will re-appear in its metallic form. It will be found that the air thus recovered, to all appearance, resembles common air, so far as being elastic, transparent, colourless, and inodorous. However, it is very different from that portion of air which the mercury originally refused to absorb: that portion instantly extinguishes flame; whereas, if a newly extinguished taper, the wick still ignited, be immersed in a portion of the air recovered from the mercury, the taper will re-kindle, and burn in it with increased splendour.

From these experiments, the obvious inference is, that we have separated common atmospheric air into two other airs, diametrically opposite in at least one property, and both of them perfectly different from the original. One of these airs is so far different from the atmosphere, that it extinguishes flame; and the other is so far different, that it re-kindles the flame, which the original air could not have done.

Since, in these experiments, the most remarkable facts to be observed are, that one kind of air causes bodies to burn with far greater splendour than they do in the atmosphere, and the other extinguishes flame, it should follow, that if the two be mixed together, an air should result, which in its power of supporting flame would be

a mean of those which compose it. Accordingly, we know this to be the case; for the two airs were obtained from atmospheric air, it being composed of them; and every one knows that, in the atmosphere, a candle burns precisely in the moderate way which might be inferred from the contrasted nature of the two constituent gases.

The air in which the taper refused to burn is of so noxious a kind, that it would extinguish life as well as flame: this fact has been established by immersing small animals in it. From its destructiveness to life, it is called *azote*.* The air, which had been absorbed by the mercury and recovered, and which favours combustion, has the effect of sometimes communicating to combustibles a sour taste; and from this circumstance it is called *oxygen* † gas.

The sum, then, of all the preceding details is as follows: — It has been shown, that by certain processes, as heating mercury in air, a portion of the air is absorbed, and another portion is not. The unabsorbed portion extinguishes flame and life; it is called azote: the absorbed portion, when recovered, supports flame and life in an eminent degree, and is called oxygen. It appears that atmospheric air is composed of these two gases — oxygen and azote; the proportion being $\frac{1}{5}$th of oxygen, to $\frac{4}{5}$ths of azote, both estimated by volume or bulk under the same pressure.

Oxygen and azote have a very decided affinity for each other; and although, in the atmosphere, their elasticity may oppose their combination, their union may be effected by certain processes, and then the change of properties resulting from combination is of the most striking kind. It is only necessary to confine a quantity of atmospheric air, or any other mixture of oxygen and azote, in a small glass tube, one end only of which is open, and plunged below the surface of mercury, to cut off the communication of the external air. If through this confined air a long continued suc-

* *α*, *a*, NO; and *ζωη*, *zoe*, LIFE.
† *οξυς*, *oxus*, SOUR; and *γεννάω*, *gennao*, I GENERATE.

cession of electrical sparks be passed, the mercury will gradually rise in the tube — indicating a diminution in the bulk of the confined air; for the gaseous particles have, by some unknown agency of the electric sparks, been forced into closer contact, and within the reach of their affinity for each other.

If the air contained in the tube be examined after this process, it will prove to be very materially altered. Instead of being inert, as originally, it is now pungent and caustic. If brought in contact with water, it is in part absorbed, and the water acquires an acid taste, and also the remarkable property of changing the blue colour of vegetable infusions to a brilliant red, when mixed. Any substance, whether solid, liquid, or gaseous, which possesses this property of converting vegetable blues to red, and which has a sour taste — although this latter is not indispensable — is called in chemistry an *acid;* and acids form a well-defined class of bodies. Thus, vinegar and lemon juice are acids; so also is the gas under consideration, produced by passing electrical sparks through common air, or any other mixture of oxygen and azote.

If the water which absorbed this acid gas be gently boiled, it will be found that the steam which flies off does not carry the gas along with it. It is possible to vaporise almost all the water; and, in proportion as it evaporates, the acid becomes stronger: at length it becomes exceedingly powerful; and so corrosive or caustic, that it will stain the skin yellow, and even destroy it and form an eschar. It is, in other respects, exceedingly powerful. A quantity of it, swallowed, will in a very short time destroy life; and it exhales a smoke which is highly prejudicial if taken into the lungs. Thus is the mild and wholesome atmosphere, the medium of health and life, convertible into the most destructive of all poisons; and by no other means than lessening the distance between its constituent particles, so as to permit the affinity of its elementary gases to operate, and a true chemical compound to be produced.

This acid is now known to exist in nitre; it is procured in large quantities from this source, and hence it is called nitric acid.

Oxygen and azote form no less than five combinations beside that of common air; yet all these are perfectly different in their properties. It may be here observed, that, when bodies combine with oxygen, the substance resulting from the combination is often, but not always, an acid; and whenever it does not possess the properties of an acid, it is called an *oxide*. Very often, oxides, by being combined with an additional dose of oxygen, are converted into acids: but in many cases an oxide will combine with a new dose of oxygen without becoming an acid, and will merely form a second oxide; and even a third and fourth oxide may be thus produced. But when the compound acquires the property of reddening vegetable blues, it then is entitled to the name of acid. Whenever there are these successive stages of oxidation, each stage is marked by the name. Thus, when any substance has united with its first dose of oxygen, the resulting substance is called a *protoxide*, from the Greek word πρῶτος (*protos*), *first*: when the second dose is taken up, the compound is called a *deutoxide*, from δεύτερος (*deuteros*) *second*; the third dose is expressed by the name *tritoxide*, from τρίτος (*tritos*), *third*: but when an oxide contains as much oxygen as it can unite with, no matter whether it is the second, third, or fourth, it is called *peroxide*, from the Latin word *per*, very much: and if there is only one combination, provided it be not an acid, it is simply called *oxide*. Other systems of nomenclature are also employed.

The property of oxygen which, to an ordinary observer, would appear the most striking, is its power of supporting that process called, in common language, burning; but in chemistry, *combustion*.

With such force does oxygen promote combustion, that not only ordinary inflammable substances are burned with surprising energy in it, but even iron itself burns with the most dazzling brilliancy. All that is required

is, to introduce an iron wire, to one end of which is attached a bit of burning candle-wick, into a phial of oxygen: it takes fire, scintillates, combines with the oxygen, and melts into white-hot globules. These have metallic lustre, and, like the original iron, are attractable by the magnet: yet they contain all the oxygen which disappeared in the process: they are now an oxide of iron.

In the constitution of the atmosphere we have ample scope to admire the design and execution of a structure calculated, with such wondrous precision, to fulfil its purposes. Were the atmosphere to consist wholly of oxygen; and the different kinds of objects which compose, and are found upon, the globe, to remain what they are; the world would run through its stages of decay, renovation, and final destruction, in a rapid cycle. Combustion, once excited, would proceed with ungovernable violence; the globe, during its short existence, would be in a continual conflagration, until its ashes would be its only remains: animals would live with hundred-fold intensity, and terminate their mortal career in a few hours. On the other hand, were the atmosphere wholly composed of azote, life could never have existed, whether animal or vegetable, and the objects of the Creator in forming this world would not be fulfilled. But the atmosphere is a wholesome mixture of these two formidable elements, each neutralising the other's baneful influence. The life of animals quietly runs through its allotted space; and the current of nature flows within prescribed limits, manageably and moderately.

SECTION II.

THE WATERS.

The ocean, along with rivers, lakes, and springs, are objects which, after the atmosphere, claim our attention. They shall all be considered under the general name *water*.

To an ordinary observer, water might appear, what it was once believed by philosophers to be, a simple element; not composed of other ingredients, but of the same nature throughout. This is far from being the case; and that it is a compound is easily demonstrated.

Every one must have observed, that, when water is thrown on a hot fire, or when a very hot iron is sprinkled with water, there is a disagreeable and peculiar smell evolved, be the water ever so pure. If the fire be exceedingly hot, like a forge, the water will blaze somewhat like ardent spirit thrown on it. If a bar of iron, heated to whiteness, be partially immersed in water, the water discharges a kind of air, which takes fire from the iron, and burns for a moment.* This air may be collected by passing the white-hot iron, or a coal ignited to whiteness, under a bell-glass filled with water, and inverted, in a vessel containing water.† Bubbles of gas will be generated abundantly at the iron or coal, and will rise to the top of the bell. By heating the iron bar several times, and immersing it, and, after each immersion, hammering it a little so as to detach some black scales that form on it, the bell may be filled with gas. Better methods will be given hereafter.

This gas has two remarkable properties: it is exceedingly light, being scarcely more than $\frac{1}{15}$th of the weight of the same bulk of common air.‡ It is very inflammable: a stream of it will burn, on the application of an ignited body, with the emission of intense heat,

* Hassenfratz, Schultz, and Beltancourt. † Lagrange.

‡ When bulks or volumes of gases are mentioned, they are understood to exist under the ordinary atmospheric pressure, unless the contrary is expressed.

but little or no light; yet a lighted taper immersed into a phial of it will be instantly extinguished. This gas is, therefore, of a nature quite different from the two gases which have been already described: it does not resemble oxygen, or azote, or any of their compounds.

It has been stated, in the last section, that iron may be burned in oxygen gas. In the experiment there described, it was observed, that the iron wire, in burning, melts down into black, brittle globules, no longer metallic, although they have a lustre approaching the metallic; and still attractable by the magnet, although now an oxide of iron. In the experiment, just now described, with the white-hot iron bar, it is observable that the scales hammered off are an oxide of iron, in every respect the same as the former. Now, whence was the oxygen derived, which thus united with the iron? The only substances concerned are iron and water: it is, therefore, an unavoidable inference, that the oxygen was derived from the water, and that oxygen is one of its component parts. The experiment may be made in a manner which renders the truth of this position quite manifest. Let the steam of boiling water be passed in at one end of an iron tube, containing iron turnings or borings, the tube and contents being kept at a bright red heat: let a flaccid bladder, from which the air has been previously well squeezed out, be tied at the other end of the tube: the bladder will speedily be distended and filled with the gas in question; the iron turnings will be converted into the same oxide of iron. The passing of the steam over the iron may be continued until the whole of the water has been converted into steam, and thus forced through: the results are the same to the last: inflammable air incessantly passes through the tube, and oxygen is continually absorbed by the iron. When the water is exhausted, both processes cease; and there are no other products.

It must be inferred from these facts, that water is resolvable into oxygen and inflammable air; and that it is composed of these two gases. It might also appear that

this conjecture could be brought to the test by mixing the two gases, and thus ascertaining if water can be formed by their union. On making the experiment, we find that the two gases, when mixed, remain unaltered: their particles seem to be at such a distance from each other, while in their elastic state, that they are not within the limits of each other's affinity. But by lessening the distance, as by forcing the two gases into a very small compass, by means of a powerful condensing syringe, they combine, and with the peculiarity of producing a loud report, as well as a vivid flash; for, under ordinary circumstances, whenever they combine they burn. This experiment is violent and dangerous, and the result of the combination cannot in this way be determined. But inflammable air may be burned in a small stream in a vessel filled with oxygen; they then combine quietly, and the sides of the vessel are soon covered with streams of liquid, which trickle down to the bottom. This is water.

The result of this slow combination of the two gases is just what was anticipated: water has been formed; and it may be admitted as a fact, analytically and synthetically proved, that water is composed of oxygen and inflammable air. It may appear surprising, that from a large volume of gases only a few drops of water are produced; but when it is recollected that the gases were in their elastic state, and that now they have parted with that heat which caused them to be self-repulsive and voluminous in bulk, the wonder ceases: the heat with which the gases have parted was that which constituted the flame. As inflammable air is thus proved to be the most remarkable ingredient in the formation of water, this gas has obtained the name of *hydrogen* *, signifying *water-forming*.

Between oxygen and hydrogen there is a remarkable difference, which deserves notice. Hydrogen is a combustible body: but if a burning body be immersed in it, the combustion is extinguished. If a burning body be introduced into oxygen, the combustion goes on with by

* ὕδωρ, *hudor*, WATER; γεννάω, I CREATE.

far greater intensity: but oxygen itself cannot by any means be made to burn; it is therefore incombustible, although it supports combustion. From facts of this kind, a distinction of bodies into *combustibles* and *supporters of combustion* has been made, and a classification of all the bodies in nature has been founded on the distinction. This is, perhaps, unfortunate; the propriety of it depends on the meaning of the word combustion: and the definition of combustion which would render the distinction proper is too restricted, and calculated greatly to perplex the theory of that process, as will appear hereafter.

During our examination of air and water, we have arrived at the knowledge of some important and striking facts. We have seen that the wholesome air, which is indispensable to the life of animals, contains the elements of destruction: and that the most incombustible of all bodies, water, is composed of the elements of fire. In short, we have obtained an acquaintance with oxygen, azote, and hydrogen,—substances which hold the most prominent place in creation: and we have learned that these bodies, by union with each other, form others of agencies just as extensive. Oxygen and azote form a powerful acid, possessed of violent properties; oxygen and hydrogen form a passive compound, chiefly remarkable for its inertness: but of the action of hydrogen and azote on each other, whether they combine, and if so, of what nature the compound may be, we as yet know nothing. If hydrogen and azote, both in the elastic state, be mixed, no change follows: but we are not to be so far misled by this fact as to conclude that there is no affinity between them: we have learned by the experience of azote and oxygen, as well as of oxygen and hydrogen, that although powerful affinities may subsist, some management is often required to induce a combination. Accordingly, a mixture of oxygen and hydrogen, when forced to an approximation of particles by mechanical compression, actually lose their elasticity, and combine with explosion, forming water. If hydrogen

be divested of its elasticity, and presented in this state to azote, an union takes place equally, and a compound is produced possessed of energetic properties, and very different from those of its component elements. But the hydrogen is not to be deprived of its elasticity by mechanical compression, as in the former case: the same object can be effected by a much more easy method: let the hydrogen be presented before it has acquired elasticity, at the very moment of its birth as we might say, or, as chemists express it, in the *nascent* state. Although, in the processes just now described for obtaining hydrogen, heat was made use of for liberating that gas from its combination with oxygen, it is to be observed, that heat only hastens the subversion of the affinity which holds the elements of the water together: the same changes may be effected without elevation of temperature, but they will take place very slowly. If iron filings be mixed with water, minute bubbles of hydrogen will at length be seen to form round the particles of iron: the oxygen does not appear, for it combines with the iron. The hydrogen becomes visible, because each particle of it has received the caloric necessary to its existence as a gas. But if the mixture of iron filings and water be confined in a vessel containing nothing but azote, the azote will exert its affinity at the very instant when each particle of hydrogen has been eliminated from the water, and before it has had time to derive the necessary heat from the surrounding media. In this state of things, a combination takes place; the hydrogen does not make its appearance, and the azote actually disappears; and when we come to examine the contents of the vessel, we find neither azote nor hydrogen. On opening the vessel, instead of an inodorous mixture of gases, as pure hydrogen and azote would be, it has acquired a smell of great pungency, identical with that emitted from what is called *smelling salts* or *hartshorn*, both of which owe their qualities to its presence. Water absorbs this gas with avidity, and affords a liquid having the same smell, a pungent caustic taste, and the

property of reddening, or even blistering, the skin when applied to it.

In treating of the atmosphere, it was stated, that, when oxygen and azote are combined in a certain ratio, a compound is produced which possesses the property of changing vegetable blue colours to red; and it was mentioned that this property constitutes the quality called acidity. We have now to examine whether the compound produced by the combination of azote and hydrogen possesses this quality. If some of this pungent liquid be added to water in which violets had been infused, the blue colour will be instantly changed, not to red, but to green; and the same will happen to any other vegetable blue: or, the vegetable blue having been already reddened with an acid, if a sufficiency of this compound of hydrogen and azote be added, the red colour will disappear, and the original blue will be restored; and if still more of the compound be added, the blue will be changed to green, just as if no acid had been ever added.

There is here not only a difference, but a decided opposition of properties. What the acid does, this compound undoes: it not only destroys the redness occasioned by the acid, but it communicates a colour characteristic of itself.

As the term acidity is attributed to bodies which have the power of reddening vegetable blues, so to the quality of rendering vegetable blues green a peculiar term has been appropriated; it is called *alkalinity;* and the bodies which possess this property,—for it will be hereafter seen that there are many,— are called *alkalies.* They possess another power, also, over vegetable colours; they convert yellows to a deep red, or, rather, brown: and the infusion of the dye-stuff called turmeric is used for this purpose.

It may excite wonder that such importance should be attached to the apparently trivial circumstance of changing the hues of vegetables, as to induce chemists to invent terms indicative of generic distinctions amongst bodies,

founded on this quality. But the cause of wonder vanishes when we learn that the effect on colours is merely an easy test, a visible announcement, that each of these classes possesses a distinct set of properties. We connect each change of colour with the possession of a certain set of properties; and, by the application of this test of colour, we infer the existence, and attribute the possession of a whole series of properties to each class.

Acids and alkalies are considered as opposed to each other in their nature, and each presenting a kind of reverse property to the other. They have, generally, a powerful affinity for each other; and, obeying that affinity, they counteract and lessen each other's characteristic effects. Thus, an acid has a peculiar taste, expressed sufficiently by its name; it is sometimes so powerful as to be corrosive and poisonous. An alkali has also a peculiar taste, quite different from an acid; it also is often caustic and poisonous. If both of these violent and pernicious substances be mixed, we might fairly expect to have a compound doubly violent and pernicious. But the reverse is the fact. If, to an acid of this kind, a small quantity of an alkali be added, the sourness of the former is diminished, it is less corrosive, and less poisonous: a little more alkali produces a little more diminution in the power of the acid; and the same happens with further additions, until, at length, the properties of the acid are completely null,—it is no longer sour, no longer corrosive, no longer pernicious, and it no longer reddens vegetable blues. It is, in short, destitute of effect on colours: its taste is salt and cooling; and in its general properties it is comparatively inactive. These changes are produced in consequence of the affinities of the acid and alkali having been satisfied: the ratio of their quantity is such, that the point of *saturation*, explained in the chapter on affinity, is attained, and there is, consequently, a total change of properties, as is always the case when active affinities have been in operation. But if, after this point of saturation has been attained, the addition of alkali be

continued, the neutral and inactive state of the compound no longer subsists: it now begins to assume acrimonious qualities; it again acts on vegetable colours: but these effects are attributable to the redundant quantity of alkali above what was necessary to saturate the acid. For, while the alkali was saturating the acid, and destroying its peculiar powers, the acid was producing a corresponding change in the alkali: the latter was at length deprived of its power of converting vegetable blues to green, as the acid was of altering them to red. But after the alkali had completed the saturation, any further additions of it could effect no other change, and, therefore, must remain independent and unaltered. This state of mutual saturation, where the peculiar powers of both bodies are suspended and concealed, is called *neutrality;* and the neutral compound is denominated a *salt*, because it generally has a saltish taste. The salts thus arising from the combination of acids and alkalies are generally disposed to undergo that symmetrical arrangement called crystallisation, which was explained in the chapter on cohesion; and each separate regular form is called a *crystal.*

It does not, however, follow that a salt must be neutral, because neutral compounds are designated salts: on the contrary, salts may either manifest the possession of acid or alkaline qualities. In such cases the salts are not neutral, and yet they may have been saturated; for it does not follow that neutrality and saturation should always accompany each other. It is possible that an alkaline body may unite with such a quantity of acid as saturates it, although it still manifests alkaline properties, and is not neutral.

The substance with which an acid is combined in a salt is called its *base:* thus, the alkali is called the base of the class of salts just described.

Having thus explained the nature of alkalinity, and having taken advantage of the first opportunity that occurred, to show how this property is opposed to acidity, how the two qualities counteract and saturate each other,

and produce neutrality, we must return to the compound of hydrogen and azote, which was under consideration, and from which this digression was made in order that the nature of saturation and neutrality might be more fully explained.

In volcanic countries, a mineral is found which occurs in crystals, and in masses of a grayish, yellowish, or brownish colour; its taste is sharp, burning, and saltish. The quantity obtainable in a state of nature is so very insufficient to supply the demand, that it has been an object at all times to form it artificially, and the ingenuity of man has supplied it in abundance. It was once manufactured in large quantities in Egypt, near the temple of Jupiter Ammon; and, deriving a name from the place whence it was obtained, it was called *sal ammoniac*,—a name which it commonly retains to this day. At present it is manufactured in vast quantities in Britain, for it is used extensively in the arts. By itself, it has no smell; but when it comes in contact with lime, it discharges a pungent and suffocating vapour, easily recognisable as identical with the pungent gas produced by the combination of nascent hydrogen and azote. If the powder of sal ammoniac be mixed with quicklime in a bottle, and a bladder be tied round the mouth, the common air having been previously pressed out, there will be an extrication of gas from the bottle as soon as heat is applied: the bag will become inflated by the newly formed gas: it will resemble atmospheric air in its physical properties, such as being transparent, colourless, and elastic: but its smell identifies it with the alkaline gas already described as composed of hydrogen and azote. The identity is confirmed by the facility with which the gas is absorbed by water, by the smell of the water thus impregnated, by the caustic taste, and the power which it possesses of changing vegetable blues to green. It will also saturate and neutralise acids. This volcanic salt, therefore, as well as that artificially obtained, holds the alkaline gas in its substance; it is its basis; and the alkaline gas has been

named *ammonia*, or ammoniacal gas, from the salt which gives origin to it. Water absorbs upwards of 400 times its bulk of this gas, and acquires some of its properties; the compound is hence called *liquid ammonia*. During the absorption of ammoniacal gas by water, the liquid becomes hot: for the caloric which was latent in the gas, and maintained it as such, becomes sensible as soon as the gas changes its state to that of a liquid, according to a law already explained: hence the temperature rises. At the same time that the gas is thus absorbed, the solution suffers a permanent expansion, for the resulting liquid is specifically lighter.

If liquid ammonia be heated, the ammonia takes back the caloric which it parted with when it was first condensed in the water; it resumes the gaseous form, and flies off in the state of gas. From the circumstance of its *flying off*, liquid ammonia is said to be *volatile;* and the term is applied to all other substances which pass off in vapour or gas at a low temperature.

It has been shown that acids and alkalies have a mutual affinity; that they combine and form salts. The name given to a salt is contrived to be an index to its composition: it consists of a genus and a species: the acid contributes the generic portion, and the alkali the specific. Thus, the name *nitrate of ammonia* is given to the salt formed from nitric acid and ammonia. Chemists are acquainted with a vast number of salts.

SECTION III.

EARTHS AND METALS.

When the almost endless diversity of objects is contemplated, which present themselves in our survey of the mineral products of the earth, one might at first be inclined to abandon the attempt of studying their habitudes as impracticable, but for the agreement of many of them

in characters which naturally suggest a classification. Thus, there are a number of bodies which correspond more or less in the following properties:—They are hard, heavy, and opaque; insoluble in water; they possess a peculiar kind of brightness or splendour; admit of being so highly polished as to be good reflectors of light; are capable of being melted by heat, and of recovering their solidity by cooling: most of them may be extended by hammering, and some into the thinnest films. These bodies are called *metals*; and many different kinds are known. They are of various colours; and they require different degrees of heat to melt, or, as chemists say, to *fuse* them.

We find minerals which evince some of the properties of metals, as opacity, great weight, sometimes splendour, and at all times convertibility to the metallic state: these are metals combined with other bodies; they are called *ores*; and it is in this state that metals occur in nature, and from it that metals are extracted.

We find minerals which possess some lustre, much weight, hardness, and transparency: they are insoluble in water, often infusible in the fire, and little alterable by heat, unless the most intense: they assume regular crystalline forms. These are called *stones*. Sometimes they are of decided and beautiful colours, perhaps transparent, exceedingly close and hard in texture, and smooth and brilliant in fracture. These are called *precious stones* or *gems*.

There are mineral bodies which, in their external characters, resemble the preceding class, but are distinguished very decidedly in others. They are in beautiful and regular forms; they possess lustre; are sometimes coloured; they are generally acted on by a moderate heat; and are very frequently dissolvable, or, as chemists say, *soluble* in water. These are called *native salts*, to distinguish them from salts which are prepared artificially.

Other minerals are distinguished chiefly by their combustibility; such are sulphur, bitumens, coals, &c.

In the mineral, as in the vegetable kingdom, we find

a variety of acids and alkalies ready formed, which, if they are not peculiar to minerals, are at least found amongst them in considerable quantity.

As to ores and metals, no further notice need be taken of them in this division of the work: their place in creation, and their nature in general, are sufficiently known to every one. Rocks, stones, and earths appear dissimilar to each other: the hardness, closeness of texture, and weight of the former, seem to distinguish them from the looseness, softness, and lightness of the latter. Yet observation shows that the nature of all of them is the same: stones and rocks are often found mouldering into earth, and earth is known to harden into stone. The process of mouldering produces no change further than breaking down the cohesion of the rock: accordingly, we find the soil at the foot of rocky mountains to contain the same ingredients as the rocks themselves.

With regard to earth, very little palpable difference can be perceived in the great bulk of it; it is apparently much the same in all parts of the world. But rocks and stones are found in every variety of aspect, and composed of very different materials. Now as these, when broken down into small particles, or powder, constitute earth, chemists have denominated the ingredients of which rocks and stones are composed, *earths;* and these are, consequently, of different kinds.

The beauty of the precious stones has brought them into such general request for ornamental purposes, that their external characters are well known. Notwithstanding their valuable qualities, they are, with two or three exceptions, composed of the same materials as the commonest stones. In the following account, such minerals only shall be noticed as make us acquainted with some new substance.

The sapphire is, in point of value, second only to the diamond: it is of various colours; but the blue and red are most esteemed, the red being more valuable. Sapphires are brought from Ceylon, and other Oriental

countries, as well as from some parts of Europe. The red sapphire is commonly called Oriental ruby, and the yellow kind is the Oriental topaz. These stones, when rubbed, often emit a phosphorescent light.

The sapphire is almost entirely composed of a peculiar kind of earth, which, singular to say, is one of the most abundant and common in nature, notwithstanding the great value set on the gem. The same kind of earth constitutes the basis of all clay soils; it is the ingredient which gives porcelain earth and potters' clay the plasticity and ductility that permit it to be moulded into the various kinds of china, delft, &c. It is the chief ingredient in pipe-clay and in common roofing slate. It is named by chemists *argillaceous earth*, or *alumina*. In every 100 grains' weight of blue sapphire, 92 are pure alumina; and it owes its beautiful and much valued colour to so small an admixture as 1 grain of iron in every 100 of the gem.

The next of the precious stones which it is necessary to describe is the *amethyst*. The kind most generally known is of a purple colour, although it occurs of other hues. The most esteemed are those brought from Ceylon and India; those next in value are the Brazilian: they are found also in Ireland, although of inferior beauty; and in many other parts of the globe. The amethyst is composed of a basis quite different from the kind last described; but, like the last, it is abundantly diffused throughout nature. Every one is acquainted with the stone called *flint*; it is very common, and therefore of little value; yet it is composed of the same materials as amethyst: the latter contains, in 100 grains, 98 of a peculiar substance, which, from *silex*, the Latin name for flint, is called *silica*. Of the same substance as the amethyst and flint are composed the gems called carnelian, cat's-eye, rock crystal, Egyptian jasper, and opal. The last, distinguished by the name of precious opal, is one from most beautiful of gems, and yet contains, in 100 grains' weight, nothing more than 90 grains

of silica and 10 of water. Notwithstanding the high price and beauty of these stones, the material of which they are composed constitutes the great bulk of the sand which lies valueless on our shores.

Silica is an essential ingredient in glass, in all sorts of pottery, and in artificial gems and enamels. It is abundant in nature, and sometimes constitutes the bulk of mountains.

It was, some years since, believed that silica is an earth analogous to those already described; but it has been discovered that this is a mistake, and that it is of a very different nature. It has been here described amongst the earths, merely because it is the basis of a number of precious stones; and its real nature, as far as known, will be pointed out hereafter.

There are some gems of great beauty and value composed chiefly of silica, but containing also alumina; as the garnet; the Brazilian topaz, which must be distinguished from the Oriental; and the Occidental or precious emerald, of which the beryl is a species.

The emerald and beryl are not, however, entirely composed of silica and alumina, but contain also another earth, with which it is necessary to become acquainted. From its property of forming combinations which have a sweet taste, it has been named *glucina*.

There is a peculiar substance, until lately considered an earth, which constitutes the great bulk of the gem called *hyacinth*. This stone is found in various countries; but the most valuable is from Ceylon, which is the repository of all rich gems. Hyacinth occurs red, brown, yellow, and green: every 100 parts of the stone contain 70 of the substance under consideration. It was first discovered in a species of hyacinth called the zircon, and hence has been named *zirconia*. Besides other places, the zircon is found in Scotland. Its nature is not fully determined.

The last of the gems which introduces to our knowledge a peculiar earth, is one that is known only to

mineralogists; it is called gadolinite, from the name of the Swedish chemist, Gadolin, who discovered that mineral. In this stone was found the earth in question, and it obtained its name from the place where the mineral was found: it has been called *yttria*, from Ytterby, in Sweden. Its physical characters are not very different from those of the preceding earths.

In introducing the student to the knowledge of the preceding earths, the gems have been adduced as examples, on account of their containing them in great purity, and as substances with which being familiarly acquainted, we acquire a knowledge of their component earths with less of the difficulty and abruptness attendant on a new science. We now take leave of these, and proceed to consider the nature of a much less costly class of minerals, although, in point of utility, some of them are of far greater importance.

Every one is acquainted with the stone called marble; its diversified hues, or its pure whiteness, and its lustre when polished, have introduced it as a beautiful material for ornamental architecture and sculpture. Marbles are of all varieties and mixtures of colour. Notwithstanding their value, they are the same substance with common limestone and chalk, with a slight difference only in purity. Limestone is one of the most abundant minerals in nature: it sometimes constitutes the substance of whole mountains.

The burning of limestone is a process common in most parts of the world. The stones are broken small, and stratified with fuel in a kiln, which, when set fire to, heats the stone red-hot. During the burning, the limestone becomes much lighter. It is now called quick-lime, or roche-lime, and its properties are totally changed. Water poured on it is immediately absorbed, and the lime appears as dry as ever. In some time, however, it swells, bursts, grows hot, discharges steam, and falls to powder. This powder is called slaked lime. The same phenomena are exhibited by marbles and chalk after burning, if similarly treated.

There are two minerals very different from limestones and marbles, and from each other, which, however, agree with limestone in the property of affording earths that, when cold water is poured on them, become suddenly hot, and undergo the process of slaking. These minerals are named carbonate of baryta and carbonate of strontia; and, from these names, the two earths obtained from them are called *baryta* and *strontia.*

Baryta is distinguished amongst the other earths by being a violent poison, and also by being the heaviest of all the earths: hence its name. Strontia is not a poison. The only remaining earth is one that is well known as an extensively used and popular medicine; this is called *magnesia.* It exists in various minerals; one of which, found in America, consists, in 100 parts, of 70 magnesia and 30 water.

The preceding earths are all which the ingenuity of chemists has been able to discover; and of these are composed all the gems, stones, rocks, mountains, and soils, that are found throughout, and constituting, the globe. Some of these minerals contain but one earth; others two; and others so many as four. From this examination we learn, that the solid parts of the globe, as far, at least, as human industry has discovered, are composed of a few earths and metals, each being presented under an astonishing variety of forms; and it will presently be shown, that the distinction between earths and metals, evident as may it appear, is not well founded. It had long been observed, that the properties of earths very nearly resemble those of the compounds of oxygen and metals called metallic oxides: but it remained for the chemists of our own day to prove what their predecessors had so sagaciously suspected; and, of late years, it has actually been demontrated that earths are themselves metallic oxides. This has been shown by the very simple method of abstracting oxygen from them; and determining that, in each case, globules of a peculiar metal made their appearance. To metallise the earths,

it is only necessary to subvert the affinity subsisting between the metallic basis and the oxygen, by means of some body having either a naturally stronger affinity for oxygen than the basis, or made to have it by art. The oxygen being withdrawn from the compound, the basis will make its appearance in the metallic state. But although the description of this method seems simple, and easy of accomplishment, there are difficulties in the way, and such as require the exertion of no ordinary skill to surmount. What these means are, it is not here necessary to detail; it is sufficient to say, that it was chiefly through the application of the powerful agent called *galvanism* that the difficulty was overcome: but the mediation of natural affinities was sometimes sufficient. When any of these earthy metals was presented, at an elevated temperature, to the action of oxygen, the latter was absorbed, and the original earth was reproduced. The metals obtained from the earths are named aluminum, glucinum, yttrium, calcium, barium, strontium, magnesium. To this list a new metal has lately been added: it has obtained the name of thorium; being extracted from a mineral of a very complicated nature, called thorite.

It appears, therefore, from the investigations of modern chemists, that the globe of the earth is one vast mass of metals of different kinds, disguised by various substances, but chiefly by oxygen.

There are three substances found in each of the kingdoms of nature, which, in their properties and composition, are nearly related to the earths, and are in daily use in arts, manufactures, and domestic economy: they are called potash, soda, and ammonia. They all possess the properties of an alkali in a high degree; and, indeed, in many respects resemble each other. There is also another alkaline substance, which belongs to the same class, but differs in being exclusively of mineral origin: the name *lithia* has been given to it, significant of its stony origin. Potash, soda, and lithia,

have been proved to be of the same constitution as the earths; and metals of extraordinary properties have been produced from them by abstracting oxygen. On account of the sources from which they are obtained, the metals are called potassium, sodium, and lithium. Ammonia, although powerfully alkaline, and analogous in its qualities with potash, soda, and lithia, differs from them in the circumstance of not being a metallic oxide; and, in this respect, agrees with a numerous class of alkalies to be noticed hereafter. Its composition has been already explained: it consists of hydrogen and azote, neither of which is known to be metallic. As these four substances evince the possession of alkaline qualities in so high a degree, they are named, by way of eminence, *the alkalies:* but some of the earths possess the same properties, although in a much less degree, and are called *alkaline* earths; such are lime, baryta, strontia, and magnesia. To this property the substances called alkalies superadd another, namely, solubility in water: potash and soda dissolve in water readily, and in large quantity. Ammonia exists in the gaseous state, and is largely absorbable by water. Lithia is but sparingly soluble; so also are lime, baryta, and strontia: hence lithia is, in this property, connected with the earths; but it is separated from them by its caustic, acrid taste. Potash, soda, and ammonia, are easily soluble in strong spirit of wine: lithia is not so; and this, again, connects it with the earths.

Opposed to the alkalies and earths, in properties, are the acids of which some mineral substances are partly composed; and which we find in the mineral kingdom, existing in an uncombined state also, and sometimes on a scale of immense magnitude. There is, in the island of Java, a volcano called Mount Idienne, from which the Dutch East India Company have been often supplied with sulphur for the manufacture of gunpowder. At the foot of this volcano is a vast natural manufactory of that acid commonly called oil of vitriol, although it is there diluted largely with water: it is a lake about 1200

French feet long; the water of which is warm, of a greenish white colour, and charged with acid, from the surface of which a slight smoke rises. Towards the southwest, the lake discharges itself, and forms a river of the same acid. The taste of this liquid is sour, pungent, and caustic: it kills all the fish of a river into which it flows; gives violent colics to those who drink of it; and destroys all the vegetation on its banks. When a little is evaporated by heat, pungent sulphurous vapours arise, similar to those discharged from the volcano, and some sulphur is deposited. From this account, it is plain that there is some intimate connection between the acidity of the liquid and the sulphurous fume occasioned by the incessant combustion of the sulphur. The water seems to have absorbed these vapours, for these very vapours are exhaled when it is heated; and that such vapours are sufficient to cause the acidity, any one may convince himself, by the simple experiment of burning some sulphur in a glass globe full of air, in the bottom of which a little water lies: vapours are formed, which the water absorbs; it becomes sour to the taste, and now reddens vegetable blues. Such is, in fact, the very process that is continually going forward in the volcano; and the result is this acid in enormous quantities, produced by the combination of sulphur with oxygen derived from the atmosphere.

Chemists had long been acquainted with the acid under consideration; but it was only within a century that it was known to be produced by the burning of sulphur: from the origin of the acid, chemists have given to it the name of *sulphuric acid*. It was formerly called *oil of vitriol*, because it was distilled from a substance of mineral origin, called *vitriol*, on account of an imperfect resemblance to green glass; *vitriolum* being the diminutive from *vitrum*. It is now manufactured in Britain on an immense scale, by the burning of sulphur; its uses in the arts being extensive.

This lake is found to contain also another acid, with properties quite distinct from those of the sulphuric. If

a quantity of its water be subjected to the process of boiling in a glass flask with a bent neck, called a *retort*, so that the steam which passes over into the neck shall be there condensed into liquid, we obtain this second acid. It has been found in various products of other volcanic countries, by Spallanzani, Vauquelin, Breislak, and others. The last of these observers found it in a form which, in itself, is a characteristic sufficient to distinguish it from the sulphuric: he found it in a state of vapour, as a permanent gas; at least, so far permanent that it would remain a gas for ever if not brought in contact with water. This fact shows that liquidity is not the state in which this acid exists in its most simple form: the liquid consists of the gas dissolved in water; for such is the affinity subsisting between them, that the elasticity of the gas is subdued.

The celebrated traveller and philosopher Humboldt found it in a number of warm springs in Mexico, scattered over a space of forty square leagues of volcanic country.

It appears that this acid is contained in vast abundance throughout the great body of waters which surrounds the globe; although not in a free and independent state, but combined with soda and magnesia. It has, on this account, obtained the name of *muriatic acid*, indicative of its being an ingredient in sea-water.

According to the analogy of the acids already described, we should suppose muriatic acid to be compound. That it is a compound, and what its component parts are, it is easy to evince. Let a mixture of oxygen and muriatic acid gas be passed through a porcelain tube, one end of which is red-hot, and the other cold: a quantity of water will be found condensed in the cold end. Now, the elements of water are oxygen and hydrogen: we have supplied the oxygen in the experiment; but whence came the hydrogen? There was no other body present to supply it but the muriatic acid; we must, therefore, infer that hydrogen is one of the constituents of muriatic acid, and we should

expect to find the other still in the tube. On examining the tube, we find that it contains a gas very different from the original muriatic acid. If passed through a vegetable blue colour, it no longer reddens it, but totally deprives it of all colour: it is now much less absorbable by water; the solution has not an acid, but an astringent taste; and the colour of this gas is greenish, although the original one was colourless. The new gas does not extinguish flame, as muriatic acid gas does; on the contrary, various bodies, when immersed in it, take fire spontaneously. In short, the gas found remaining in the tube is in every respect different from the original muriatic acid gas.

This new gas, in consequence of the green colour, which is a distinguishing character of it, has been named *chlorine**; and its compounds with other bodies are called *chlorides*. From the experiment, the results of which have been stated, it appears that muriatic acid can be resolved into chlorine and hydrogen: hence these two gases, when united, compose muriatic acid; and hence this acid has been also named hydrochloric acid, in allusion to the two gases of which it is compounded.

Chlorine is an abundant element in the mineral kingdom: it is found in combination with the metal sodium: the compound is rock-salt. In sea-water it is associated with two singular substances, called *iodine* and *bromine*, both of which resemble it in many respects. The most striking quality of iodine is, that, when heated, it expands into a violet-coloured gas, which, on cooling, crystallises again into its original form. Bromine is a poison; a violent caustic; and is capable of setting fire to metals, by mere contact, at common temperature.

The basis of sulphuric acid, as already observed, is *sulphur*. This highly inflammable substance is found abundantly in the neighbourhood of volcanoes, crystallised in a state of purity. It exists, combined with metals, in a number of ores; and in some of these,—as

* χλωρος, *chloros*, GREEN.

that of the copper-mines of Fahlun, in Sweden, and the isle of Anglesea, — it is associated with a substance exceedingly similar to itself in all its properties. This substance is called *selenium*. Its most easily recognisable quality is, that, when in the state of vapour, it smells strongly of horseradish; and one of its compounds, if snuffed up the nostrils, produces catarrhal symptoms, with violent cough.

Section IV.

ORGANISED STRUCTURES.

Notwithstanding the perplexing diversity of form which vegetable substances assume, experiments have proved that they are all composed of the same ultimate materials; and these very few in number. We may select any vegetable structure as the representative of all the rest; and, by examining others in the same manner, it will be found that they present the same results.

The method by which the component elements are separated is simple; the vegetable is merely exposed to the action of fire, — not an open fire, for in this way all its parts would be dissipated or burned away; but in a vessel calculated to retain its principles in such a manner as to permit their being brought under examination. Green wood will be a good instance. Take a common gun-barrel, the touch-hole of which is stopped; push a small cylinder of green wood down to the breach, and place that end horizontally in a good coal fire. As the wood is heated, the water, which is the chief ingredient of its juices, distils over, and drops from the open end of the tube. In proportion as the water distils, from being insipid it becomes sour. Shortly after, a gas issues out of the tube, and may be collected by tying a moist bladder, the common air being

well pressed out of it, round the mouth of the tube. If, when the gas ceases to issue, the contents of the tube be examined, the piece of wood will be found altered into a black, dry, light, sonorous mass, retaining, however, its texture, though much reduced in size. It is, in short, converted into charcoal, or, in chemical language, *carbon;* and if its weight be added to that of the gas, the mere water, and the sour water, the result will be the original weight of the wood without loss: hence these are all the ingredients which composed the wood.

Charcoal is a substance so well known that it is unnecessary to describe it. One of its most commonly known properties is combustibility: if a bit be kindled, and a current of air supplied to it, it will burn almost entirely away, leaving only a few white ashes of little weight. In common air it burns with no great brilliancy; but if the experiment be made in oxygen gas, it burns with considerable splendour.

A remarkable circumstance attends the combustion of charcoal in oxygen, which is introductory to a fact of importance. Notwithstanding that the experiment is made in a glass vessel from which there is no escape, the charcoal totally disappears. It will also be found that the oxygen is completely altered in its properties. In its original state, a lighted taper immersed in it would burn with the utmost brilliancy; it might be left in contact with water without absorption or change; and, if the water were coloured with a vegetable blue, its tint would remain unaltered. But, after the burning of the charcoal in it, it manifests the reverse of all these properties: instead of increasing the brilliancy of a burning taper immersed in it, the taper will be instantly extinguished, as would also the life of an animal; if it be left in contact with common water, it will be absorbed, the water acquiring a sharp taste, which is now capable of turning vegetable blues to red. These properties distinguish sufficiently the gas

which remains after the combustion of charcoal. The question occurs, what has become of the charcoal and oxygen? for both have disappeared. A moment's reflection supplies the answer: the charcoal and oxygen were originally in the glass vessel; nothing has escaped from the vessel; and, hence, the new gas which fills it must consist of the two bodies that disappeared. The change of properties which ensued, proves that a chemical combination has taken place between them: the charcoal was reduced to particles so small as to be invisible; these combined with the oxygen, and a compound gas was produced, consisting of these two ingredients, which, as it possesses the property of reddening vegetable blues, is an acid in the gaseous state. This gas has received a name indicative of its origin; from the Latin word *carbo* (coal), it is called *carbonic acid gas*. Under ordinary circumstances it is invisible, transparent, colourless, and elastic like the atmosphere.

The beverage called soda water is almost entirely composed of water holding carbonic acid dissolved. It is the presence of this gas in some wines that causes their sparkling quality, and their effervescence; it also constitutes the sprightliness of bottled ales, and produces the foam by its entangled efforts to escape. If a bit of charcoal be kept red-hot for some time in carbonic acid, will be diminished in weight, because some of it has dissolved in the gas; and it will be found that the resulting gas is quite changed in its properties. Carbonic acid reddens vegetable blues; the new gas does not affect them: carbonic acid is not inflammable; the new one is very much so, and will burn with a blue flame. The quantity of charcoal contained in this new gas is just twice the quantity contained in carbonic acid; 100 grains of oxygen uniting with 37 to form the acid, and with 74 to form the new gas.

According to a system of nomenclature already explained, the compound of charcoal and oxygen, in which the oxygen exists in such quantity as to produce an acid,

is called carbonic acid gas; but the other one, in which the oxygen is insufficient to produce an acid, is called *carbonic oxide.*

A striking proof of the extraordinary differences of appearance which the same body may assume, and also of the intrinsic worthlessness of some of those objects on which society sets the highest value, occurs in the instance of the substance under consideration. Every one knows the enormous price at which diamonds of good quality and size are estimated. The celebrated Regent diamond, which was set in the handle of the late emperor Napoleon's sword of state, is now valued at 260,000*l.*, although it weighs only about $1\frac{1}{8}$ ounce, and was originally purchased for 20,400*l.* by Thomas Pitt, grandfather of the great earl of Chatham, while governor of Madras. Yet this precious ornament is neither more nor less than a piece of charcoal; and, surprising as it may appear to those hitherto unacquainted with the fact, it is well proved, by numerous experiments, that, between the diamond and charcoal there is almost no difference of composition: the diamond burns in oxygen with brilliant flame, and, like charcoal, forms carbonic acid; like charcoal, it forms steel by combination with iron; and the difference between the two bodies seems to be chiefly in their state of aggregation, the diamond being harder and crystallised. It is also a little purer in composition. The pure portion of charcoal is distinguished among chemists by the name of *carbon.*

It has been already observed, that, during the heating of a piece of wood in an iron tube, a large quantity of gas is given off with an acidulous water. The nature of this gas is next to be enquired into. If a burning body be applied to it, as it issues from the iron tube, it will take fire, and burn with a white voluminous flame, somewhat like a common gas-light. This property distinguishes it from the two inflammable gases already described — hydrogen and carbonic oxide; the former of which burns with the emission of scarcely any

light, and the flame of the latter being blue. If the gas from wood be burned in a slender stream passing from a bladder furnished with a pipe, and if the combustion be performed in a glass globe filled with oxygen gas, the globe will in a short time become dull on the interior, owing to the condensation of watery vapour, and this constantly increasing, it will at length trickle to the bottom, and a quantity of water will be found there. The formation of water is a sufficient proof that hydrogen constituted a portion of the gas burned in the experiment. But the globe, instead of containing oxygen, as it did originally, is now filled with a gas easily recognisable as carbonic acid by its sharp smell, its capability of being absorbed by water, and its communicating to the water the peculiar acerbity of that gas. The production of carbonic acid proves that carbon was present in the gas obtained from wood, and we cannot detect in it any other element than carbon and hydrogen, they being in a state of chemical combination, and forming a distinct variety of gas. On account of the two elements which constitute this gas, it has been called *carbureted hydrogen*,—a name comprising several varieties; the differences arise chiefly from the relative proportion of the constituent ingredients.

Beside these gases, there are hydrogen, carbonic oxide, and carbonic acid, present in wood gas.

In this analysis of wood we obtain, as already observed, a liquid of a sour taste, capable of reddening vegetable blues, neutralising alkalies, and, in short, possessing all the properties of an acid. It was once believed to be different from all others known, and obtained the name of *pyroligneous acid*, indicative of its being produced from wood by fire. It has the taste and smell of tar; for common tar is obtained by exposing wood to a strong but smothered heat, and this is just what happens to the wood enclosed in an iron tube. A process has been contrived for separating the tar from the acid, and then the acid discloses its nature, its smell being no longer disguised: it proves to be vinegar; it is made

on the large scale from wood, and is an excellent kind for many purposes on account of its great strength and purity. When made as strong as possible, it obtains the name of *acetic acid*, from the Latin word *acetum*, vinegar.

We now perceive that the exposure of wood to a high temperature affords a great number of compounds: there are two combinations of carbon and oxygen, at least two of carbon and hydrogen, and one which comprises the elements of the former two. We see that pure hydrogen is also extricated, and we find that a little azote existed in the wood; for it combined with hydrogen, and formed ammonia, which is found neutralised in the acetic acid. These, with the charcoal, are the results of the process; and as a general summing up, we may recapitulate, that from wood we obtain hydrogen, carbureted hydrogen, bicarbureted hydrogen, carbonic oxide, carbonic acid, acetic acid holding tar, ammonia, and charcoal. By multiplying experiments on other vegetable structures, we learn that all of them, however complicated, when made to undergo the ordeal of heat in confined vessels, resolve themselves, like wood, into the four elements — oxygen, hydrogen, carbon, and azote; the latter being in such small quantity as to be barely discoverable. These, again, by combining amongst themselves, produce the compounds above described; but the four ingredients mentioned are what are called the ultimate elements of all vegetable matter, notwithstanding its apparent diversity.

The subject selected for elucidating the constitution of vegetable matter was wood, because it is a fair representative of all other vegetable bodies when submitted to *destructive distillation*, as exposure of any decomposable matter in close vessels at a high temperature, so as to collect the products, is called. But it is only when submitted to destructive distillation that wood can be considered as the representative of other vegetable matter; and when we look to the ultimate products of

the distillation, namely, oxygen, hydrogen, carbon, and azote.

These are called the *ultimate elements* of vegetables, because the decomposition has proceeded to the *last* stage that is attainable in their analysis. But besides these, and their immediate combinations formed during the destructive distillation of vegetable matter, there are other combinations which naturally exist in the vegetable structure, and which offer themselves to our observation without being subjected to any complicated process. These combinations, being the *nearest* to the natural constitution, and the more immediate objects of sense when we examine any vegetable organisation, are called the *proximate* principles of vegetables.

It will not be necessary in this place to describe the vegetable proximate principles; they will come in hereafter: they do not need any introductory remarks, as they exist ready-formed, and offer no difficulty to an easy comprehension of their state of existence in nature.

Having acquired some acquaintance with the vast variety of form under which the objects constituting the vegetable world appear, and the simplicity of their composition, the next subject of contemplation is the animated part of creation, — the most interesting and stupendous of all. How much more admirable and surprising must the structure of a living animal appear, when it is known that it is composed of but a few elements such as have been formerly described, — little more than the meanest vegetable, and fewer than many minerals.

The materials of which animals are composed being nearly the same as those which compose plants, the difference is in their relative quantity, and in the mode of combination. The combustible substance, phosphorus, has been detected in small quantity in some vegetables, as in the onion: but it exists in large quantity in the bones of animals, — not in the state of phosphorus as commonly seen, but disguised by combination with oxygen in the state of an acid, and this acid combined

with lime. The bones of animals, then, consist chiefly of lime and phophoric acid: at least these ingredients compose their earthy basis, as it is called; but it is impregnated with animal matter that adds greatly to their strength, toughness, and solidity. The other element which exists largely in animal matter is azote: it is also a constituent part of several kinds of vegetable matter; and it is singular that the same azote which adds so much to the nutritiousness and flavour of animal food, renders vegetable matter disgusting to the taste, and poisonous. This will appear more fully when we come to consider the proximate principles of plants called vegetable alkalies, which are known to be highly azotated, and which are all bitter and deleterious. Mushrooms also contain much azote, as I infer from the circumstance which I have often observed, that their juice, during putrefaction, generates a large quantity of ammonia; for this consists of hydrogen and azote. There cannot be a more deadly poison than some mushrooms. It is an illustrative fact, that mushrooms, on account of containing so much azote, approximate very closely in flavour to animal food. During the destructive distillation of animal and vegetable matter, we find differences of results corresponding with their difference of composition: animal matter gives rise to the production of ammonia, — a powerful alkali; and vegetable matter affords a product of quite an opposite nature, — the powerful acid, vinegar.

The chief substances, then, which enter largely into the composition of animal matter, are oxygen, hydrogen, azote, carbon, phosphorus, lime. We also find some other kinds of matter, as certain acids and metals, but in quantity so small as not to affect the truth of the above statement, that the foregoing six ingredients constitute the great bulk of the animal fabric.

PART II.

ARRANGEMENT AND EXAMINATIONS OF THE ELEMENTS OF BODIES.

CHAP. I.

ELEMENTS, OR SIMPLE SUBSTANCES, AND THEIR IMMEDIATE COMBINATIONS.

In chemistry, the word *element* means what is otherwise called a *simple substance*; — one that is not known to contain more than one kind of matter. When a substance is known to contain two or more different kinds of matter, it is called a *compound*. The metal iron is a simple substance; it is of the same nature throughout, and no other kind of matter can be extracted from it: but rust of iron is a compound, for it may be resolved into metallic iron, oxygen, and carbonic acid. It is probable, however, that many of the bodies which chemists at present consider simple, may be hereafter discovered to be compound. The expression, simple substance, is not to be understood as conveying any positive affirmation concerning the nature of that substance, further than that it has not been proved to be a compound.

Section I.

OXYGEN.

Oxygen gas is a permanently elastic fluid; that is, one which no compressing force or degree of cold hitherto applied, has ever condensed into a liquid or solid. It is

is transparent and colourless: 100 cubic inches of it weigh 33·9153 grains; and, as the same bulk of common air weighs 30·8115 grains under the same circumstances, the specific gravity of oxygen must be 1·1007.*

Oxygen gas may be obtained by the following process: Procure a cast-iron bottle, with a tube of iron ground air-tight into its mouth. Such are now commonly sold by the iron-founders for chemical purposes. Into this introduce a quantity of black oxide of manganese,—an article sold by most druggists; fit in the tube, and bed the bottle in a good coal fire, building small bits of coal all round, so as to heat the bottle to a bright red. Oxygen gas will soon begin to be extricated abundantly. In order to collect it let a bottle be filled to the top with water, and cork it so that the cork having excluded its own bulk of water, the bottle remains full. Invert the bottle, plunge its neck under water, and take out the cork under water; the bottle will still remain full. The bottle and the vessel of

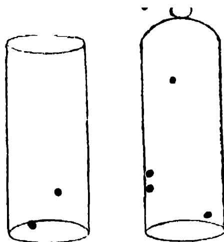
* This determination is so different from 1·111, the specific gravity adopted by the chemists of Great Britain, that I think it necessary to assign my reasons for giving it above. According to an experiment which appears to have been made with every attention to accuracy, by Dr Thomson, 100 cubic inches of dry oxygen gas, at a mean pressure and temperature, weigh 33·9153 grains.—*First Principles*, i. 65.

According to sir G. Shuckburgh Evelyn, 100 cubic inches of common air weigh 30·5 grains. But the estimate given by Biot is different (*Traité de Physique*, tom. i. 145.). Biot says, that under a pressure of 0m.76, and at the temperature of melting ice, a litre of dry atmospheric air weighs 1·3 gramme. In another place he gives another determination which scarcely differs from this: and Thenard (*Traité de Chimie*, i. 234), without mentioning the authority, gives 1·2991 gramme as the result of experiment. We may, therefore, consider 1·3 gramme as the weight of a litre of dry air, according to these authorities.

A litre, calculated from captain Kater's determination of the metre, is equal to 61·0270 cubic inches. A gramme I estimate at 15·4223 grains; and, although the estimates of the gramme, and of the equivalent of the litre, differ from what is to be found in tables, I believe them to be correct, having gone over the calculation several times. The equivalent of 0m. 76 is 29·9218 barometrical inches. The cubic inch of water at 62° has been found to weigh 252·458 grains; that is, 252·506 grains at 60°. Taking these estimates as data, and converting the pressure, temperature, and volume of air given by Biot into English inches and grains, I find, that, according to him, 100 cubic inches of dry atmospheric air weigh 31·123 grains.

But sir G. S. Evelyn and M. Biot are entitled to equal confidence, and their experiments were made with great attention to accuracy. It is, therefore, proper that we should take a mean of both: the mean of both numbers is 30·8115 grains; and this is the weight of 100 cubic inches of air. If this be admitted, we obtain the specific gravity of oxygen by the following proportion:—30·8115 : 33·9153 : : 1·000 : 1·100735, as in the text.

water should be previously so arranged that the end of the iron tube can be plunged under the surface of the water; or, if the iron tube be not long enough to reach the vessel of water, a tin or copper tube may be slipped on the end of the iron one, and a piece of wet bladder tied over the juncture. The gas will bubble up through the water: the first portions will be common air, contained in the iron bottle and tube expanded by heat. When this has been allowed to escape, slip the mouth of the glass bottle over the end of the tube, so that the bubbles of gas may enter the bottle. In proportion as gas enters, water will leave the bottle; and when it is filled with gas, put in the cork and remove it; or, without putting in the cork, pass a cup into the water, under the mouth of the bottle, and remove both bottle and cup — the latter remaining filled with water, so as to prevent gas from escaping, or common air entering. Other bottles may then be filled in succession. If cylindrical



jars, or bell glasses, are to be filled, they may be treated in the same manner, being first plunged down into water so as to fill them, and then raised up with the mouth downward, taking care that the mouth always remains an inch or two under water, so as to prevent common air from entering. The most convenient vessel for holding water for these purposes is a trough or cistern made of wood or japanned tin, with a shelf about two inches under the intended surface of the water, for supporting jars or phials while they are filling with gas. The shelf is not absolutely necessary. This vessel is

called the *pneumatic trough,* and is useful in all cases where gases are concerned, unless the gas be absorbable by water. It will, in procuring oxygen, be advisable that a little newly slaked lime be dissolved in the water: for this will more certainly absorb any carbonic acid that may be derived from impurities or adulterations in the manganese, both of which are often found in that of commerce.

If a cast-iron bottle cannot be procured, one of the iron bottles in which mercury is imported may have an iron tube fitted to its mouth. Or, if this method is not available, the following may be employed: — Let a common Florence oil flask have its mouth strongly wound round with cord for an inch downwards, in order that it may not be burst by tightly fitting a cork to it. Let a perforation be made in the cork with a round file, and a glass tube inserted into it. Manganese is to be introduced into the flask; sulphuric acid is to be poured on, in quantity sufficient to wet it thoroughly; and they are to be mixed. The cork and tube being pushed in, and the whole made air-tight, the heat of an Argand lamp, or the flame of a cup of burning spirit of wine, is to be applied. In a short time oxygen gas will come over, the first of which is to be rejected as containing common air.

Or some nitre may be introduced into a gun-barrel, the touch-hole of which is closed: a piece of common gas-pipe may be fitted air-tight by luting a wet bladder to its mouth, the other end terminating in the water cistern. The end of the gun-barrel containing the nitre should then be heated in a good coal fire to redness. Gas comes over, but towards the end of the process becomes impure: it contains azote, and should be rejected. Or in place of nitre, the mercurial oxide, sold by druggists under the name of *red precipitate,* may be poured into the iron pipe and heated. This is a more expensive method: to furnish 113 cubic inches of oxygen, a troy ounce of red precipitate must be used. When of ordinary purity, this oxide contains

no nitric acid, and therefore will not afford any compound of azote: if any be feared, the first bubbles will contain it all. Mercury, in its purest state, distils over with the oxygen; and it may be of use for thermometers and barometers, or for experiments. The red precipitate, heated dry in the oil flask over a charcoal fire, will furnish oxygen also; but the heat must be barely sufficient, or it will melt the flask. In this case the neck must be wound with annealed thin iron wire, not with cord: the glass tube must fit in without the intervention of cork, and the juncture must be rendered air-tight by cementing it round with a soft adhesive substance called a *lute*. The lute, which answers in this and almost every other case, is very finely powdered pipe-clay; not that which is made into white-balls artificially, but the rough material as purchased from the druggist. This powder should be mixed in a mortar, with as much boiled linseed oil, otherwise called drying oil, as will form a mass like putty used by glaziers. It must be pounded with a heavy pestle for a length of time, during which it will become much too firm; more oil should then be added, and the pounding resumed. The oil must be added and the pounding continued, while the mass becomes hard in consequence. The lute is now made, and ought not to be applied in any case without wiping the parts to be joined perfectly dry: and the juncture should be made smooth and regular by rubbing it over with the finger. When the lute is intended to be kept for store, it should be pressed into a pot, and tied over with a wet double bladder. This kind of lute, for there are many others, is distinguished by the name of *fat lute*.

Some of the properties of oxygen gas have already been noticed; the remainder will come in under future heads. When suddenly and violently compressed, it gives out heat and light. M. de Saissy says, that none of the gases but those that contain oxygen give out light; and that itself gives out the most. Chlorine, however, is known to emit light. It has been

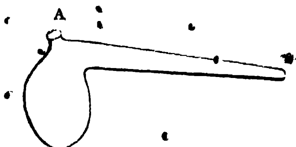
stated by Mr. Hart (*Brande's Journal*, xv. 66.), that the light which sometimes appears at the muzzle of an air-gun, when it is discharged, arises from attrition of accidental sand or hard substances adhering to the wadding. He loaded an air-gun with bits of sugar, quartz, fluor spar, &c., and discharged them: light was produced; but not when care was taken to avoid such substances in the wadding.

Section II.

HYDROGEN.

Hydrogen gas is a permanently elastic fluid, transparent and colourless. It is exactly sixteen times lighter than oxygen: hence, dividing 1·1007 by 16, we have 0·0688 for the specific gravity of hydrogen*: 100 cubic inches of it, therefore, weigh 2·1197 grains. It is between fourteen and fifteen times lighter than atmospheric air. The following is the process for obtaining it: —

A glass *retort* must be procured; they are sold at all glass-houses and chemists' shops, although generally very ill-formed: the shape is given in the figure. It



should be blown without any imperfection in the substance of the glass, such as tears or stones: it should be very thin in all parts, but particularly in the bottom; for no glass vessel that is not thin will bear sudden heat

* Dr. Thomson (*First Prin.* i 71.), from carefully executed experiments, gives 0·0694 as its specific gravity: but he took sir G. S. Evelyn's estimate of atmospheric air as the basis of his calculation. If we take the mean of Evelyn's and Biot's estimate (see page 134), then Thomson's experiment gives 0·0688. Berzelius and Dulong found it 0·0688. These coincidences render it pretty certain that the number given in the text is correct.

without cracking. The retort should be *tubulated*, that is, it must have a mouth at A, either fitted with a cork or an air-tight ground glass stopper; the latter mode is expensive, and seldom necessary. A number of small iron nails should be introduced through the tubulature one by one, cautiously, to avoid breaking the glass. The nails should then to a good deal more than covered with water, and sulphuric acid about equal to the weight of the nails should be poured in. Ebullition commences in the retort, owing to the rapid formation of gas in the liquid, just as steam would appear in water while boiling; and gas is expelled through the *beak* or long neck of the retort. The end of the beak should be plunged in water, and some of the gas allowed to escape, for it is mixed with the common air of the retort. The hydrogen gas may then be collected in bottles or bell glasses, filled with water in the manner already directed. When the gas begins to come over slowly, nearly the same quantity of sulphuric acid may be added, which will renew the ebullition, and gas will continue to be discharged until all the iron is dissolved. Small pieces of zinc may be used in place of iron nails.

This kind of ebullition is called by chemists *effervescence;* the word merely means the extrication of any permanently elastic gas in the form of air-bubbles.

Hydrogen gas, as commonly obtained, has a disagreeable smell, somewhat resembling phosphorus: but it may be so far purified as to be quite free from smell, by being shaken in a bottle, with a little alcohol holding potash in solution, or with a very large quantity of water. It cannot be breathed for any length of time without occasioning death: a few cautious inspirations may be taken, it is said, with no other effect than attenuating the voice for a while. It is, however, a rash experiment. A frog lives for a long time in it.

In consequence of the lightness of this gas, compared with the atmosphere, it will ascend when at liberty, just in the same manner as a cork plunged by force to the

bottom of a vessel of water would rise to the surface if left to obey the law of specific gravity.

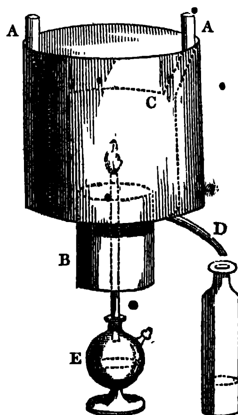
If a pig's bladder of large size be filled with hydrogen, its outer coat may be peeled off bit by bit, until the whole becomes specifically lighter than the air, and then it will ascend in the manner of an air-balloon. The allantois which invests the fœtus of the cow, procurable from any butcher, or the craw of a turkey, will afford an excellent material for a hydrogen balloon.

If a burning taper be plunged into a jar of hydrogen, the taper will be extinguished; yet hydrogen gas is very combustible, although it will not support combustion. The *philosophical candle* is a bottle fitted with a cork, through which passes a slender glass or metallic tube. The materials for generating hydrogen being introduced, the cork and tube are fixed in air-tight: hydrogen gas will be discharged abundantly. Some should be allowed to pass off, in order to expel the common air present; for without this precaution an explosion would happen on kindling the gas. The application of a burning body, or an electric spark, even the most feeble, will set fire to this jet of hydrogen; and it will burn slowly and quietly while the effervescence continues. The flame shows almost no light, but its heat is intense. Let a small thin bladder, squeezed tight so as to expel the common air, be filled two thirds with hydrogen and one third with oxygen: the orifice being tied, make a pin-hole in the bladder, and apply the hole to the flame of a candle; an explosion will take place as loud as a pistol shot, and the bladder will be shattered, although the hand that holds will not be injured. There will also be a vivid flash of light. I have seen a person incautiously explode a very large ox bladder filled with these gases, holding it close to his side while the tube proceeding from it was applied to a candle: the explosion was equal to a musket shot, and he was thrown with violence against a wall which he stood near; but sustained no injury. It should be here observed, that explosions of this kind, in which

the noise is considerable, are called by chemists *detonations* (from *detonare*, to thunder).

The combustion is so violent, that the result of it cannot be ascertained by making the experiment in this form. In a former chapter, the product was shown to be water. But by burning the philosophical candle in a large balloon containing oxygen gas, a combination between the two gases takes place in the flame, and the resulting water is instantly dispersed in steam throughout the balloon, and will condense on its sides if it be kept cool; the water will gradually trickle down, and will slowly accumulate in the bottom. The method is altogether unsatisfactory, and very troublesome. But every purpose is as well answered by employing atmospheric air instead of oxygen, and the following cheap apparatus may be made by any tin-plate worker.

Let a tin-plate cylinder, A A, be made, open at the top and closed at the bottom, except where the small



tin cylinder B, open at both ends, enters it, and is soldered to it. Let another tin cylinder, C, close at the top, be fixed inside the cylinder A A, and soldered all round B, with two slanting pipes, A A, proceeding from the

top, and opening into the air in the manner of flues. Let the cylinder A A be filled with cold water. It is manifest, that if the two-mouthed glass vessel E, in which hydrogen is generating, be placed so that its pipe shall pass through the cylinder B, and rise into C, the jet of gas having been previously set fire to, the steam of water formed in the flame will condense on the surface of the inside cylinder C, by the coldness of the external water in A A, and will trickle down the sides of C, and eventually run out at the pipe D, into the bottle there placed to receive it. Within C the oxygen of the common air is continually withdrawn; and it would therefore be filled speedily with azote—the other constituent of the atmosphere—but for the two slanting flues A A, which allow it to pass off, while cold air from the bottom passes in to support the flame. In this way water, in any required quantity, may be generated; but if the water in the external cylinder A A becomes warm, cold water may be supplied in its place. The water thus generated is not pure; besides other impurities, it contains an impregnation of tin, which renders it a little whitish. To prevent this, the vessel may be japanned.

The relative quantities of the gases necessary to form water is well ascertained: one volume or measure of oxygen requires exactly two similar volumes or measures of hydrogen; that is, 100 cubic inches of oxygen would require 200 cubic inches of hydrogen. The weight of 100 cubic inches of oxygen is 33·9153 grains; the weight of 200 cubic inches of hydrogen is 4·239; and the latter number is one eighth of the former: hence, by weight, 1 part of hydrogen requires 8 of oxygen, and the result is 9 parts of water.

But when 1 part of hydrogen combines with 8 of oxygen, its affinity for oxygen is not perfectly satisfied; on the contrary, it will combine with as much more oxygen, that is, 16 parts in all; and then also it forms a liquid, to appearance, and under some circumstances, resembling water, but surprisingly different in all other

respects. It cannot exist at the ordinary temperature of the air (60°); for even at a degree under this, the additional 8 parts of oxygen separate from it by effervescence, and what remains is water. It must, therefore, always be preserved at a very low temperature. When dropped on certain metallic oxides, an explosion takes place, accompanied with heat and light, and the hydrogen loses half of the oxygen with which it had been combined. This compound consists of 1 part by weight of hydrogen, and 16 of oxygen: as no greater quantity of oxygen is known to combine with hydrogen, the liquid is called *peroxide of hydrogen*. No known cold can freeze it. If freely applied to the skin, the latter is destroyed. It is prepared by a difficult and complex process.

Oxygen and hydrogen do not combine by mere mixture; their elastic state prevents this: but if subjected to violent compression, or if a taper be applied, they explode, and water is formed. This mixture of gases, if heated in a tube at a degree lower than that at which it explodes, enters into combination without any explosion, and water results.

An intense heat, nearly the most powerful known, may be produced by the flame of a stream of hydrogen, forced from a bladder through a blow-pipe tied to it, directed on the substance to be heated; and another stream of oxygen blowing from a similar apparatus into the flame just where it issues from the blow-pipe.

If an avoirdupois ounce of common rod iron be dissolved in sulphuric acid diluted with water, the quantity of hydrogen evolved is 738 cubic inches: the same weight of zinc affords but 598 cubic inches.

Section III.

AZOTE, OR NITROGEN.

Azote, or nitrogen, is a permanently elastic gas, transparent, colourless, and inodorous. Its specific gravity is 0·9748 *; and 100 cubic inches of it weigh 30·0355 grains.

A number of processes have been given in chemical books for the preparation of azote, but they are tedious or troublesome, or both. The following is a method which I have found to succeed: — Take a bottle capable of containing a gallon (277¼ cubic inches), and fit a cork accurately to it: throw into it 22 troy drachms of the salt sold by druggists under the name of green copperas, or sulphate of iron, with half a pint of water; then pour as much water on 4¼ drachms of roche-lime as will slake it; and when slaked, throw it into the dissolved sulphate of iron. Cork the bottle perfectly close; and, having inverted it, immerse the neck in a vessel of water to prevent the entrance of air. By agitating this mixture briskly during a few minutes, still keeping the neck immersed, the whole of the oxygen present in the common air, which the bottle had contained, will be absorbed; and, on removing the cork under water, a quantity of water will rush in, equal to the volume of oxygen which had been removed. The air now remaining in the bottle is pure azote; its volume is 222 cubic inches, and it may be transferred into any other vessel by filling that vessel with water, inverting it so that the mouth shall be in water, then getting the mouth of the bottle under the vessel, and turning the mouth upwards: water will enter, and azote will rise into the vessel. The quantity of sulphate of iron and lime here directed, is just double what would be required by calculation; but the process is thus hastened.

* For 4 azote + 1 ox. = 5 common air: and 5 — 1·1007 = 3·8993, which, divided by 4, gives 0·9748.

If a burning body be immersed in a jar of azote, it is extinguished as instantaneously as if plunged into water. No animal that breathes can live in azote; and from this circumstance is derived its name, which signifies *life-depriver*. It is not combustible: it enters extensively into combination: it is an abundant element in animal matter; and its existence in such large quantity is a chief distinction between the constitution of animal and vegetable matter.

It has been already shown that the atmosphere is composed of oxygen and azote; in every 100 cubic inches of atmospheric air there are 20 of oxygen, and 80 of azote: hence the oxygen is one fifth of the whole volume of any measure of common air. There is great difference of opinion as to whether these two gases are merely mixed together, or whether they are in a state of chemical combination. Strong arguments have been advanced on both sides, and the question remains yet undecided. It is now no longer confined to the mere constitution of the atmosphere, but has extended to the constitution of all mixed gases.

Those who support the opinion that the two gases are chemically combined in the atmosphere, found their belief upon facts like the following:—The specific gravity of azote is less than that of the atmosphere; the specific gravity of oxygen gas is greater. Now, since a certain volume of oxygen is heavier than an equal volume of azote, we should expect, that if in the atmosphere they be merely mixed without the operation of affinity, the oxygen would at length subside to the earth, while the azote would float above it. But we know that the fact is otherwise; for air taken from the greatest elevations to which balloons ascend, affords the same relative quantities of the two gases. Atmospheric air is also of the same composition in all parts of the world. This consideration appears to favour the opinion, that between the two gases some chemical attraction subsists: but there are also considerable objections to this view of the subject.

It may be objected, that if the oxygen and azoté are thus combined, some of those chemical changes ought to be observable which indicate combination, and new properties should be evolved. But none such are discoverable; for the specific gravity of common air is the mean of the specific gravities of oxygen and azote: and its chief properties seem to be a mean of the properties of its component gases.

A view of the subject has been proposed by Dr. Dalton, which is not liable to these difficulties, although not free from objections of another kind. Dr. Dalton conceives that the repulsion which produces the elasticity of the atmosphere, does not subsist between azote and oxygen, but between azote and azote, and between oxygen and oxygen. He conceives that, with regard to oxygen, azote offers scarcely any resistance to the indefinite expansion of that gas; and that oxygen does not resist the indefinite expansion of azote. In fact, he supposes that each acts as a vacuum to the other, and that whatever pressure a particle of oxygen at the earth's surface sustains, that pressure arises solely from all the particles of oxygen above and around it, but none whatever from those of the azote; and, conversely, that a particle of azote at the earth's surface is pressed by all the other particles of azote in the atmosphere, but not at all by the oxygen. Each gas thus sustaining only its own weight, it would expand itself, regardless of the other; both would press upon other bodies, but neither would subside according to its weight. And although, at very great heights, there might be a difference of the relative proportions of the oxygen and azote, in consequence of the great total predominance of azote in the atmosphere, this could not be observed at such heights as are within our reach. He conceives that the two gases are not in any manner chemically combined.

The most obvious objection to the hypothesis of Dalton is, that were it admitted, it should follow, that by connecting a glass globe filled with oxygen, and one filled with azote, by a stop-cock, the heavier gas being under-

neath, the moment the communication is opened there should be an instantaneous mixture. Dr. Dalton made the following experiment: — A pint phial filled with carbonic acid, and an ounce phial of common air, were connected by a glass tube, thirty inches long and one third of an inch bore, so that both phials were air-tight with regard to the external air, and communicated with each other through the tube. This apparatus stood vertically, the common air phial being uppermost. In one hour, the common air phial had acquired no sensible quantity of carbonic acid gas; but in three hours, it had it in great plenty.* Dr. Dalton adduces this experiment, to prove that the ascent of the air in the lower vessel is not attributable to chemical affinity, as none subsists between the two gases; and he infers that it favours his hypothesis. It seems to be as much an evidence against his hypothesis. If each gas acted as a vacuum to the other, there ought to be an instantaneous commixture. But, to remove this obstacle, he says that the gases meet with some mechanical obstruction, owing to their minute division, while passing each other in contrary directions. Is it conceivable, that such an obstruction could exist to the transmission of two gases through a tube *one third of an inch diameter;* and that, for the space of *an hour,* there should not have passed *even the smallest quantity* of the carbonic acid gas into *a vacuum?* This experiment seems quite fatal to the hypothesis. He has adduced other experiments, made with the same kind of apparatus, but using gases which are not known to have any direct affinity for each other; such as carbonic acid gas and hydrogen. In the mixture which took place of these two gases with each other, Dr. Dalton conceives that affinity cannot be supposed to be concerned, as they are not known to have any affinity. That conclusion may, however, be questioned. It may be very true that carbonic acid and hydrogen do not manifest any affinity for each other in their gaseous state; but it is quite certain that the three elements concerned —

* Manchester Memoirs, Second Series, i. 261.

carbon, oxygen, and hydrogen — have, collectively, a powerful affinity for each other, and constitute the basis of vegetable organised matter. The obstacle to the successful exertion of their affinity, is the elastic form: but a partially successful exertion may be conceived to operate so far, that the solid elements would be retained at the limits between calorific repulsion and chemical attraction; the latter force being active in a slight degree, but not sufficiently so to effect a combination. As to similar examples, drawn from other gases which are not known to possess affinity for each other, it may be replied, that we can scarcely view affinity in any other light than as a general property of matter. When bodies do not obey the tendency of their affinity, it is because counteracting agencies are in more powerful operation. We have an example of affinity, the efficacy of which is partially resisted, in the case of charcoal, which absorbs many times its own volume of various gases, and gives them out again by being plaeed in water, or in a vacuum. If these gases permeate and diffuse themselves in a *solid*, for which they do not possess any affinity more than one kind of matter does for every other, and without combining, why may not one gas diffuse itself in another gas to which it has no more than their general affinity, in the same manner, without entering into an energetic combination, and yet without separating by difference of specific gravity? That oxygen is absorbed by charcoal, by an affinity inoperative so far that it does not produce carbonic acid, is proved by the fact, that after a long lapse of time this acid gas is really formed, although not at first.

Dr. Dalton conceives that his hypothesis receives support from the facility with which it explains the various circumstances of the existence of aqueous vapour in the atmosphere and other gases, and the difficulty of accommodating the chemical hypothesis of its solution in these gases. His arguments are the following: — Different gases are found to contain the same quantity of watery vapour, the volumes being alike:

the density of the gas makes no difference; for whether it be rare or otherwise, the quantity of vapour is the same: the same quantity of vapour would be present in the same space, even if the gas were entirely removed, and the space were left a Torricellian vacuum. Dr. Dalton suggests, that by supposing the vapour of water to exist independently of any attraction to the gas, and under no other control than its own weight, the phenomena are disembarrassed of the foregoing difficulties. But it may be observed, that it has never been proved that different gases contain the same quantity of vapour in equal volumes: the experiments of Saussure, Clement, and Desormes, merely prove that different gases impart the same quantity of water to other substances; but this may depend on the power of these substances to abstract water, and the power of the gases to resist such abstraction. Hence, until the facts be better proved, there is no occasion to seek any explanation of them; and, if the above reasoning be correct, one of the foundations on which the hypothesis rests is removed. The following considerations seem adverse to Dr. Dalton's opinions, and favourable to the chemical hypothesis: — If vapour maintains an independent existence in a vacuum or in air, being neither attracted nor repelled by the aërial particles, it follows that rarefying or condensing the air should make no difference in the quantity of vapour; as is, indeed, affirmed by Dr. Dalton himself to be the case. But Saussure found his hygrometer to indicate "dryness in the air which was rarefied, and humidity in that which was condensed*;" and hence he concluded, that "rarefied air dissolves less vapour than when it is dense." † It is even a well known fact, that when the air in a large receiver of an air-pump is suddenly rarefied by a few strokes of the pistons, vapour is actually seen falling down in mist; and this can scarcely be attributed to reduction of temperature, for Dr. Cullen found that a thermometer included in the receiver fell but two or three degrees. Such was the effect of the

* Essais sur l'Hygrométrie, Neuchatel, 1783, p. 133. † Ibid. p. 219.

heat that disappeared, no matter how great its quantity might have been.

If air does not dissolve water, or exert any affinity on it, as is supposed in the hypothesis of Dalton, how does it happen that the evaporation of water is greatly promoted by passing a current of air over its surface? If vapour be elevated from water merely by its own volatility, the passage of air over it should have no effect; or if any, it should be a counteracting one, whenever the air is colder than the water, by depriving it of some of that heat which is the means of elevating it into vapour. Many other arguments, of the same tendency, could be adduced, if space permitted.

On the other hand, it must be admitted, that the affinity of air for watery vapour cannot be the sole agency exerted in the solution. The fact that vapour pervades a Torricellian vacuum, seems to decide this point. I am inclined to think, that the agency of both heat and affinity is necessary to the explanation of the phenomena. The increased solubility of water in air, in proportion as the latter is warmer, may be explained by increase of the intensity of affinity; for heat is known in many cases to exalt its force.

As to the argument that atmospheric air is equal in volume to the sum of the volumes of the two gases which compose it, and that it possesses properties merely intermediate between those of its elements, although a certain change in them ought to result, if chemical combination had taken place between them; it may be replied, that as the affinity in effective operation is exceedingly weak, so much so as to be overcome by almost any other affinity, the change of properties should be proportionately trivial. There is an undoubted chemical compound of the same elements, in which the volume of the elements does not alter on entering into combination, viz. deutoxide of azote: and with regard to changes, there are unquestionably some observable, which are usually attributed to dilution, but which may depend partly on a weak affinity; and these are at least as striking as the

changes which take place in mixing spirit of wine with water, although in this case there seems good reason to suppose that affinity is in operation.

In fine, as we know of no two bodies which we can affirm do not possess any affinity for each other, and as there is reason to believe that this kind of attraction is as much a general property of matter as gravitation, I think we are not under the necessity of seeking the explanation of the mixture of gases on a gratuitous principle, which supposes the caloric that exists in or surrounds two particles of different kinds of matter in the gaseous state to obey a law diametrically the reverse of what we know would act upon them, if they were in the liquid or solid state.

We have now to consider those substances which are composed of azote and oxygen, and in which the elements are universally admitted to be chemically combined: there are five such; two oxides, and three acids.

Protoxide of azote.—It was stated at page 113. that nitric acid and ammonia, when combined, form a crystalline salt, called nitrate of ammonia. If a quantity of this salt be introduced into a retort, and heat gradually applied, the salt will melt, boil up, and discharge a gas, which is to be collected in the manner described at page 135. This gas is a compound of azote and oxygen: it was formerly called *nitrous oxide* and *gaseous oxide of azote*, and was discovered by Dr. Priestley. It has a sweetish taste. Water absorbs three fourths of its volume of it. It is transparent and colourless. At the pressure of the atmosphere it is a gas; but when compressed, by a force equal to about 50 atmospheres, it is condensed, and becomes an exceedingly volatile liquid, which, however, expands again with violence when the pressure is removed. It consists of 100 measures of oxygen combined with 200 of azote, both condensed into the volume of 200 measures. Its specific gravity is, therefore, 1·5252; for twice the specific gravity of azote, 1·9497, added to the specific gravity of oxygen, 1·1007, and divided by 2, gives 1·5252. Dr. Thomson ascertained by three expe-

riments, which agreed, that the specific gravity is 1·5269; a sufficiently striking correspondence. 100 cubic inches weigh 46·9931 grains. Combustibles burn in this gas: a candle burns in it with less brilliancy than in oxygen, but greater than in common air; it at length becomes surrounded with a bluish halo: sulphur, phosphorus, and charcoal, require to be well kindled before they are introduced into it, otherwise they do not burn; and an iron wire burns in it as it does in oxygen, but for a shorter time.

The most remarkable property of this gas is its effect upon animal life when breathed. If an oiled silk bag containing it, and furnished with a tube to hold in the mouth, be so arranged that a person can draw the gas into his lungs, and breathe it back and forward a few times, it will produce extraordinary sensations of a highly pleasurable kind, accompanied by an increased vividness of ideas, propensity to muscular exertion, involuntary laughter, and the greatest exhilaration, without the subsequent languor and depression that follow ebriety. Sometimes, however, in peculiar constitutions, we find the only effect, in the first instance, to be a sensation like the approach of fainting. In one instance, I saw it produce effects resembling apoplexy; but no injury was sustained. It is probable that this gas may yet be found of use in medicine.

Deutoxide of azote. — The second compound of oxygen and azote was formerly called *nitrous gas;* but, in conformity with the principles of nomenclature already explained, it is at present named *deutoxide of azote:* like the former compound, it is a gas. Protoxide of azote requires 50 measures of oxygen to 100 azote: but in order to form this deutoxide, 100 measures of azote combine with 100 of oxygen, that is, twice the bulk of oxygen contained in the protoxide: these equal measures of the two gases unite without condensation, and therefore form 200 measures.

This gas may be obtained by mixing three parts of concentrated nitric acid with four of water, both by mea-

sure, and pouring the mixture on copper wire cut into bits, and contained in a glass retort, the beak of which is plunged in water: red fumes and an effervescence appear in the retort; and when the former disappear, the gas may be collected in bottles or jars, as already described. This gas is very little heavier than common air, 100 cubic inches weighing only 31·975. As it is composed of equal measures of oxygen and azote, without condensation, it is easy to see that its specific gravity must be the arithmetical mean. Oxygen is 1·1007, and azote is 0·9748; the arithmetical mean 1·0377; and this is the specific gravity required.

If a lighted candle be immersed in deutoxide of azote, it is immediately extinguished; it also destroys animal life. Like the protoxide, it continues the combustion of charcoal and phosphorus, when these bodies are introduced already burning. This gas has not been liquefied by pressure.

Its most remarkable property is its effect on oxygen gas, whether pure, or as it exists in the atmosphere. When these two gases are mixed, they instantly assume a deep red, or orange brown colour. If 100 measures of oxygen, and 200 of deutoxide of azote, be mixed, the change of colour takes place, and the whole is suddenly condensed to 100. The resulting compound is called *nitrous acid vapour*, and is next to be described.

Nitrous acid.—The above mentioned vapour, when sufficiently cooled, is condensed into a liquid called nitrous acid. In the 200 measures of deutoxide of azote employed, there are 100 of oxygen, and 100 of azote: the 100 of oxygen added to the 100 with which the deutoxide had been mixed in the experiment, give the composition of nitrous acid as follows:—200 measures of oxygen combined with 100 of azote, that is, four times the quantity of oxygen contained in the protoxide. The 300 measures condense into 100 of nitrous acid vapour, or into a liquid, if the temperature be low. This liquid is very different from what is called nitrous acid in commerce. The real nitrous acid is very volatile; it boils at

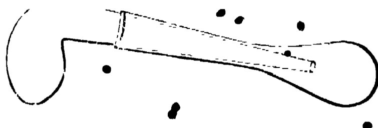
82°. Its specific gravity is 1·451: it contains no water, for it may be formed from gases which are perfectly dry. It has a powerful affinity for water: water added, changes its colour to orange, yellow, or green, according to the ratio; much water resolves it into deutoxide of azote, which escapes, and *nitric acid*, which will presently be described.

Hyponitrous acid is so named, from its containing a quantity of oxygen less than what exists in nitrous acid last described (ὑπο, under). If 100 measures of oxygen be mixed with 400 of deutoxide of azote, and the mixture is then exposed to intense cold, the whole condenses into a green liquid. The volatility is such, that it can only retain the liquid form at very low temperatures. This is hyponitrous acid: its composition is obvious, from what has been stated above; for as there are 200 measures of oxygen in the 400 of deutoxide employed, and 100 measures of oxygen were added, 300 measures of oxygen combine with the 200 measures of azote, which constituted the remainder of the deutoxide of azote. This is three times as much oxygen as exists in the protoxide. Hyponitrous acid is decomposed by water: yet if sulphuric acid be present, the three bodies enter into combination, and we obtain a compound, consisting of hyponitrous acid, sulphuric acid, and water, in the form of a crystalline solid.

Nitric acid.—There is but one more combination of azote with oxygen; in forming it the azote is saturated, and does not manifest any further affinity for that gas. It cannot be produced unless water be present, and it is known to chemists only as containing it. If 100 cubic inches of oxygen and $133\frac{1}{3}$ of deutoxide of azote be mixed, water being present, the two gases are completely condensed, and the resulting compound is called *nitric acid.* Of the $133\frac{1}{3}$ cubic inches of deutoxide of azote, one half ($66\frac{2}{3}$) consists of oxygen, which, added to the 100 of oxygen, affords $166\frac{2}{3}$ cubic inches: and the other half ($66\frac{2}{3}$) is azote. Hence, as $66\frac{2}{3}$ of azote require $166\frac{2}{3}$, by the rule of proportion 100 of azote will require

250 cubic inches of oxygen; and this, accordingly, is the ratio of the two elements in nitric acid.

Nitric acid, composed of the same elements combined in the same proportion, may be obtained by exposing a mixture of nitre, rendered perfectly pure by repeated solutions and crystallisations, with an equal weight of the strongest sulphuric acid, to a moderate heat in a glass retort: the acid will distil over into the neck, and



trickle down into the glass receiver A, provided that the long neck of the latter be kept cool by constant sponging with cold water. This acid contains about one fourth of its weight of water, derived from the sulphuric acid. If the nitre had been rendered perfectly pure by repeated solutions and crystallisations, and the heat was exceedingly moderate, the acid produced will be almost colourless: but if it contained common culinary salt, as that of commerce always does, the acid will be somewhat yellowish, on account of a little muriatic acid, which culinary salt gives origin to, and which decomposes some nitric acid. Common nitric acid is orange coloured on this and two other accounts. Pure nitric acid cannot exist without a certain ratio of water present in it. Unless the sulphuric acid be employed in sufficient quantity to afford that ratio of water, a part of the nitric acid will be spontaneously decomposed; the result being oxygen, deutoxide of azote, and nitrous acid, and the colour will, consequently, be orange. The process recommended by Mitscherlich as affording the best produce, and occasioning the least waste of acid, trouble, and fuel, is to distil a mixture of 100 parts of nitre, 96·8 of sulphuric acid, and 40·45 of water. The resulting nitric acid will weigh 135 pounds, and its specific

gravity will be 1·3. The third reason for the yellowness of common nitric acid is, because it is not always protected from the agency of light; this has the effect of partially decomposing it, and generating oxygen, which exhales, and nitrous acid, which imparts the colour. To render orange, or brown nitric acid colourless, introduce it into a retort; apply a long necked receiver as before, and expose it to heat: the brown part will rise in vapour, and be condensed in the neck. What remains in the retort is colourless nitric acid; the nitrous acid is found in the receiver.

The specific gravity of the strongest procurable nitric acid is 1·55, and then it contains exactly one seventh of its weight of water: that of commerce is about 1·423, and contains two fifths of its weight of water. Nitric acid has very opposite effects on water, with regard to the production of heat. If diluted with half its weight of water, heat is evolved: but if the water be in the state of snow, intense cold is the result. If nitric acid be poured round the rim of a saucer, on which lies a quantity of warm, dry charcoal powder, the latter takes fire, and throws up copious showers of brilliant sparks: the acid must be strong and a little warm; and the charcoal should be newly made and finely powdered. If a piece of ignited charcoal be laid on strong nitric acid, the charcoal burns with intense vividness. I have found that cantharides, perfectly dry and warm, are set on fire, if thrown on very strong warm nitric acid, contained in a glass flask. "About a tea-spoonful of nitric acid, contained in a phial and tied to a long stick, will, if poured on the same quantity of oil of turpentine, cause it to burst out into a flame with some force. If poured on phosphorus, it causes it to burn.

When exposed to 66° below melting ice, it freezes; at 248° it boils, if its specific gravity be 1·420: if it be stronger or a little weaker than this, it boils at a lower temperature: thus, acid of specific gravity 1·45 and of 1·34 both boil at 240°. Nitric acid absorbs moisture from the atmosphere, if exposed to it.

It will now be useful to bring together the chief facts detailed relating to the combinations of azote and oxygen. If atmospheric air be denied a place amongst the real combinations of these two gases, the five combinations will stand thus:—

Protoxide consists of	100 azote and		50 oxygen	or	2 to 1.
Deutoxide - -	100	-	100	-	2 to 2.
Hyponitrous acid	100	-	150	-	2 to 3.
Nitrous acid -	100	-	200	-	2 to 4.
Nitric acid -	100	-	250	-	2 to 5.

The numbers in all cases representing cubic inches or any other volume.

Section IV.

CARBON.

It has been already shown that charcoal is the substance which remains when wood or any vegetable substance is exposed to a red heat in close vessels. The best charcoal for chemical purposes is made by covering a piece of box-wood in a crucible with sand, and exposing it to an intense heat for some time after all flame has ceased on the surface of the sand. When cool, the charcoal is to be taken out, and included in well-closed bottles. If made at a red heat, charcoal is a conductor of electricity, and burns without flame: if made at a heat below redness, it is a non-conductor, and blazes a little in burning.

When charcoal is set on fire, it burns away, and leaves behind a small quantity of ashes, which consist of alkali, earths, salts, and metallic oxides. These are impurities, and should be considered as quite foreign to the real matter of charcoal. In the same light we should view a very small quantity of hydrogen which the best burned charcoal contains. The real matter of charcoal is what chemists understand by the word *carbon*; and it is this only which is to be considered as identical with the diamond (see p. 128.).

Charcoal recently made, perfectly dry, and still warm, has the remarkable property of slowly absorbing gases in very large quantities, — in some cases 90 times its own volume, — and giving them out again unaltered when immersed in water, especially if boiling.

It is probably a result of this property, that it acts so powerfully as an antiseptic, and removes the taint of meat that is in progress of putrefaction. The common mode of using it, however, for this purpose, is utterly ineffective. The meat to be recovered should be first washed extremely well several times in cold water: it should then be covered with cold water in large quantity, and several small pieces of charcoal, red-hot, should be thrown into the water when somewhat hot: the boiling must be continued as long as the meat requires it. Perhaps it is on the same account that charcoal minutely divided forms a dentifrice so useful in certain cases. What is sold in boxes can have nothing to recommend it but its grittiness, if this be really a recommendation: to correct fetor, it should be powdered with the utmost despatch in a very hot metallic mortar, and speedily introduced into a phial, which should immediately be well corked, and even sealed. When this powder is used, it ought to be exposed to the air as short a time as possible. It is a common practice to char the inside of water casks, in order to keep the water sweet, for charcoal sweetens putrid water; and to scorch the ends of timber intended to remain in the ground, to prevent its putrefaction. The bitterness of particular vegetables is destroyed by boiling with charcoal, whether animal or vegetable. Charcoal absorbs watery vapour from the atmosphere; and probably does so, and retains it, in the same manner and according to the same principle that it retains gases. There are several cases on record of the spontaneous ignition of charcoal, both dry and moist, the cause of which has never been ascertained.

The most intense ordinary heats with which we are acquainted, have no effect upon charcoal, except to ren-

der it harder, denser, and more sonorous*; that is, if no other substance is allowed to act along with the heat: the heat excited by a powerful galvanic apparatus acts upon it in such a manner as to render it probable that the charcoal had been both fused and volatilised; but the fact seems not clearly established.

It possesses the useful property of depriving various liquids of their colour, and any peculiar or disagreeable smell which they may possess. A long account of experiments on its powers in this respect, by Lowitz, may be seen in Crell's Chemical Journal, vol. ii. He recommends vegetable charcoal well burned and finely powdered; but it has since been found that charcoal obtained from animal substances is far more powerful.

Carbonic acid.—When charcoal is burned in oxygen, intense heat and light are produced: if a bit of the bark of charcoal be fixed to a copper wire, and immersed in a state of ignition in a vessel of oxygen, it throws out the most beautiful and brilliant scintillations, which fill the vessel in all parts. During this combustion, the oxygen and carbon combine, and the result is carbonic acid. There is no change of volume during the combustion, except a temporary expansion owing to the heat; we may, therefore, calculate the quantity of carbon which has combined, by deducting the specific gravity of carbonic acid from that of oxygen: — 100 cubic inches of oxygen weigh 33·9153 grains; 100 cubic inches of carbonic acid weigh 46·5973 — (*Thomson*): the difference, 12·682, is, consequently, the weight of carbon that combines with 100 cubic inches of oxygen, and that exists in 100 cubic inches of carbonic acid. Then, as 30·8115, the weight of 100 cubic inches of common air †, is to 46·5973, the weight of 100 cubic inches of carbonic acid, so would the number 1·000, or unity, be to the number 1·5123, which expresses the specific gravity of carbonic acid.

* Although it never has been volatilised, the term carbon *vapour* is used by chemists: it will be hereafter explained.

† See note, page 134.

Carbonic acid extinguishes flame: this can be strikingly shown by letting down a burning taper to the bottom of a glass jar; filling a bottle with carbonic acid, and pouring it, as if it were water, into the jar: the flame is immediately extinguished. It is equally fatal to life as to flame. The *Grotto del Cane*, or the Dog's Grotto, in Italy, is well known; it is an artificial cave, in which there is a constant natural exhalation of carbonic acid. The following feat is shown to strangers: —a man carries in a dog, and places him on the floor: the dog, if left long enough, dies; but the man is not affected; for the carbonic acid, by its weight, occupies the lowest stratum of about 18 inches' depth, and the stratum above is pure air: but that it is poisonous to man is evinced by the fate of persons who incautiously expose themselves to the vapours of charcoal burning in ill-ventilated apartments, or who venture into large vessels in which fermentation had been conducted, as in breweries, distilleries, &c.

In order to generate carbonic acid, it is not necessary to burn charcoal in oxygen gas. Common limestone, marble, chalk, &c. are all compounds of lime with carbonic acid, and the latter may be detached from the lime in all cases by pouring on an acid having a greater affinity for the lime than the carbonic acid has: a mixture of oil of vitriol and water succeeds; but muriatic acid is more convenient. Bits of chalk, or still better, marble, may be gently let fall into a tubulated retort, and diluted muriatic acid may be poured in, so as to half fill the retort: the gas may be collected in the manner already described, except that water will not be proper for the pneumatic trough and vessels, as it would absorb the gas; in this case, mercury must be used instead of water.

In order to prove that this gas is an acid, the beak of the retort, in which it is generating, may be immersed in a phial bottle, containing an infusion of blue cabbage; after a little of the gas has been absorbed, the infusion will change gradually to red: or, if we substitute lime

water for the infusion, the lime and carbonic acid will unite, and form the original chalk which was put into the retort, and which consists of these two ingredients; the chalk thus regenerated floats through the water, and renders it turbid. This is one of the characteristic properties of carbonic acid; and it may thus be detected in, or removed from, gaseous mixtures in which it exists.

Water absorbs about its own bulk of carbonic acid spontaneously; but much more may be forced into it by using mechanical pressure, as that of a condensing syringe or a powerful force-pump. The water, by this treatment, acquires the property of effervescing violently when poured out; it has a brisk, agreeable, acerb taste; and, although in other respects an acid, is not sour. If a little soda had been dissolved in the water previously to its impregnation, the result is the beverage called *soda water*. It is carbonic acid which imparts the effervescing quality to cider, perry, ales, porter, and sparkling wines; and it is the same that renders bread spongy. This acid gas is expelled from water containing it, either by boiling or freezing. By exceedingly powerful pressure the gas is condensed into a liquid; but when the pressure is suddenly removed, it recovers the elastic form with an explosion. It constitutes about $\frac{1}{2000}$th of the weight of atmospheric air at the surface of the earth; and is also found at the greatest elevation. It constitutes an ingredient in many minerals and mineral waters.

The diamond, by being intensely heated with a burning lens in oxygen gas, burns with a bright red light, and converts the oxygen into pure carbonic acid gas, just as charcoal does. Carbonic acid gas is, therefore, to be considered as a solution of diamond in oxygen gas, even when it is prepared by the combustion of mere charcoal.

Carbonic oxide.—When carbon is burned in oxygen, the oxygen is by no means saturated with carbon, as is proved by the following experiment:—Take a long earthen tube, filled with bits of charcoal, and place it across a furnace, so that it will be heated red-hot almost through

its whole length. To one end connect a bladder, half filled with carbonic acid; and, to the other end, a flaccid bladder, of the same capacity, squeezed quite empty. When the charcoal is perfectly red-hot, press the carbonic acid very slowly through the tube, so that it shall pass through the red-hot charcoal into the empty bladder; and pass it back and forward several times in the same manner. All the properties of the carbonic acid will now be changed: it will be lighter; it will be combustible, and burn with a blue flame; it will be no longer acid; it will not be absorbable by lime water; and its bulk will be exactly doubled. The new gas is called *carbonic oxide*. Were this experiment made with every attention to accuracy, it would be found that 100 cubic inches of carbonic acid weighing 46·5975 grains, are converted into 200 cubic inches of carbonic oxide, the weight of which is 59·2793 grains; being an increase of 12·682 grains, which is the additional quantity of carbon taken up in the process, and just equal to the quantity of carbon that existed originally in the carbonic acid. Hence 100 cubic inches of carbonic oxide consist of 12·682 grains of carbon and 50 cubic inches of oxygen, weighing 16·9576 grains; the whole weighing 29·6396 grains: and the quantity of carbon is double what exists in carbonic acid, consistently with the law of multiple ratio. As 100 cubic inches weigh 29·6936 grains (common air being 30·8115 grains), its specific gravity must be 0·962.

Carbonic oxide easily takes fire; it burns with a sulphur blue flame, and generates but very little heat while burning. The result of the combustion is carbonic acid; to become which, it is evident, from what has been already explained, that the carbonic oxide must combine with half its volume of oxygen, and that the carbonic acid so formed will condense into the original bulk of the carbonic oxide. Although it so readily takes fire, it extinguishes the flame of burning bodies when they are immersed in it.

This gas, if inspired, acts as a poison. Sir H. Davy

"took three inspirations of it, mixed with about one fourth of common air: the effect was a temporary loss of sensation." The case of Mr. Witter has been recorded by himself (*Phil. Mag.* xliii. 368.): he made "three or four hearty inspirations of the gas, having first exhausted the lungs of common air as much as possible. The effects were an inconceivably sudden deprivation of sense and volition. I fell (he says) supine and motionless on the floor." This happened in the laboratory of the Royal Dublin Society, in my presence. Immediately after the occurrence, while he lay on the floor, his breathing was stertorous, his face purple; and in this state he continued for half an hour. The late Dr. Wade chanced to be present; he directed oxygen to be forced into the lungs: but it did not appear to me that his recovery was attributable to this.

In order to prepare carbonic oxide, there is no occasion to have recourse to the process given above; the following seems the best: — Throw about 20 ounces of whiting into a wide metal pot, placed on a moderate fire. The damp of the whiting will soon begin to exhale; and the process of its expulsion will be exceedingly tedious, unless the matter be continually stirred with a pestle, in order that the little masses, constantly forming, may be broken down. It will be known to be dry, when these masses no longer form, and the whiting is a discrete light powder. Of this an avoirdupois pound should be returned into the metal pot, with a pound of tolerably bright iron filings, and the mixing over the fire resumed, so that the filings may be perfectly dried, and the whole well mixed. The reason of guarding so much against water is, that it would furnish hydrogen by its decomposition by the iron. The mixture should next be introduced into a cast-iron bottle, such as that described at page 134.; the whole of it will exactly fill a bottle capable of holding 1¼ pint of wine gallon measure = 36 cubic inches. The iron tube must then be fitted into the bottle, and the bottle bedded in a strong coal fire, urged continually by bellows, if it

be in a common grate. All the vessels employed should be filled with water, whitened by lime, in order that any carbonic acid given over in the process may be absorbed, and thus removed. By calculation, on pure materials and perfect decomposition, the product should be 6609 cubic inches of carbonic oxide: but it will be a successful process, if it be $3\frac{1}{2}$ cubic feet. In this process, the iron robs the carbonic acid (of the whiting, for it is merely carbonate of lime) of half its oxygen, and thus converts it into carbonic oxide. The mixture of the two ingredients should be very intimate, to avoid the evolution of unaltered carbonic acid; the great excess of iron used has the same tendency. The heat used for drying the whiting should not be so great as to expel any carbonic acid.

Carbonic oxide is not known to be susceptible of being condensed, by pressure, into a liquid. When mixed with twice its volume of air, the electric spark is capable of causing it to explode feebly. Red-hot iron or charcoal is required to set fire to it; although hydrogen, which produces so much more heat in burning, kindles from iron or charcoal heated so as to be barely visible — (*Davy*). At a red heat, carbonic oxide is decomposed by hydrogen. It possesses no acid properties, and is not absorbable by water.

Besides carbonic acid, carbon and oxygen form another acid, called *oxalic*, which will be hereafter described.

There are many combinations of carbon with hydrogen, and much uncertainty prevails with regard to their number and nature: they are all designated by the name *hydrocarbons*, or, more properly, *hydrocarburets*.

Marsh gas, or fire-damp. — The gas which bubbles from the bottom of stagnant pools, is the same as that which issues from the fissures of a coal mine: it is a carburetted hydrogen; at least nine tenths of its bulk are so; the other tenth being carbonic acid and common air. In the former case, it originates from the decomposition of vegetable matter contained in the water, and cannot be imitated by art. It has a most disagreeable smell,

which, however, does not depend upon it, but upon foreign matter; for, when well washed, it is nearly inodorous.

This gas is transparent, colourless, and elastic, like common air. When mixed with twice its volume of oxygen gas, and a lighted taper applied, or an electric spark passed through, an explosion takes place with a loud report, and carbonic acid and water are the results. 100 cubic inches of the gas require for combustion exactly 200 cubic inches of oxygen; and, after the explosion, they are found condensed into 100 cubic inches of carbonic acid. As oxygen is not altered in bulk by being converted into carbonic acid, it is evident that 100 cubic inches of the oxygen were consumed in forming carbonic acid; to do which, 12·682 grains of carbon were required, and this was the whole quantity of carbon present in the original 100 cubic inches of carburetted hydrogen. We have now only to discover the quantity of hydrogen which it contained; and, as the hydrogen was saturated with and condensed by the other 100 cubic inches of oxygen, it follows that there must have been 200 cubic inches of hydrogen present, the weight of which is 4·2394 grains. These, added to 12·682 grains of carbon, give us 16·921 grains as the weight of the original 100 cubic inches of carburetted hydrogen. We may therefore infer, comparing this with the weight of common air, that the specific gravity of carburetted hydrogen is 0·549.

Olefiant gas.—This gas, which is also called carburetted hydrogen, is similar in appearance to the former: it has no smell: 100 cubic inches of it weigh 29·6034; hence its specific gravity is 0·9608: 100 cubic inches, mixed with 300 of oxygen, and a flame applied, or an electric spark passed through, will explode violently, and the bulk of the whole will be reduced to 200,—these being carbonic acid gas. Hence the original gas consisted of 200 cubic inches of hydrogen (= 4·2394 grains) and 25·364 grains of carbon, all condensed into 100 cubic inches.

Bicarburetted hydrogen was originally called *olefiant*

gas, because, by combination with hydrogen, it forms a liquid which has an oily appearance. In burning, it produces a dense, white, and voluminous flame, which illuminates strongly. It may be copiously generated by heating a mixture of one measure of alcohol with three of concentrated sulphuric acid in a retort: an effervescence takes place; and a gas comes over, which, after a little has escaped, is received in jars in the usual way, using water, whitened by lime, in the pneumatic trough, that any carbonic or sulphurous acid may be absorbed.

When this gas is several times passed through an intensely heated earthen or metallic tube, it is partially decomposed, and it suffers a great diminution of illuminating power. It may be totally decomposed by a current of electrical sparks.

Carburetted and bicarburetted hydrogen bear very different relations to the well-being of man: the former, when a spontaneous production of nature in mines, is one of the most terrific instruments of destruction, and a great obstacle to human industry; for, by mixing with a certain quantity of common air, it acquires the property of exploding when accidentally kindled; and thousands of human lives have fallen sacrifices to its violence, until the splendid invention of the safety lamp divested it of its terrors. Bicarburetted hydrogen is the chief, although not the most abundant, ingredient in *coal gas*, now so generally used for illumination: the other ingredients are carburetted hydrogen, hydrogen, and carbonic oxide. Coal gas is made by introducing a quantity of bituminous coal into a large iron cylinder called a retort, close at one end, and furnished with a mouth-piece at the other, for closing or opening it: there is also a tube for carrying off the gas and other products as they form. A quick, strong heat is applied round the cylinder; and a vast quantity of gas, composed of the four ingredients just mentioned, is thus extricated, with tar and an ammoniacal liquor, both of which are condensed by passing through pipes im-

mersed in cold water. There is a great difference in the relative proportions of the gases in the mixture, as also in the quantity of tar, according to the quality of the coal, and the mode of applying the heat. The more tar the gas holds dissolved, the more dense will be the flame when the gas is made to burn, and the more disagreeable will be the smell when it is not burning. A slow heat gives much tar and little gas, and that little of a poor quality: a quick heat gives much gas of good quality, and less tar. Owing to these and other causes, the illuminating power of coal gas varies much. Before it is let through the conducting tubes for public consumption, it is well agitated in contact with a mixture of lime and water, or passed through strata of loosely strewed hydrate of lime: it is thus deprived of much of its smell, but also of some of its illuminating power. On on average, a chaldron of good Newcastle coal, weighing 25 cwt.*, will afford 12,000 cubic feet of gas, provided that the retorts are new. After being used a few months, the product will not exceed 11,000 feet, or even 10,000. On the whole year, the average may be about 11,000. The quality of this gas is such, that half a cubic foot per hour is equivalent, in burning, to the light of a mould candle of six to the pound, during the same space of time: hence, one pound weight of coal will afford light equal to such a candle for 4½ hours. An illuminating gas of this kind is sometimes presented ready-formed by nature. A village of Fredonia, in the western part of the state of New York, is lighted with this gas as it naturally issues from a rock: the flame is large, but not quite so brilliant as that of coal gas.

Oil gas may be prepared in the following manner: — A large iron cylinder, containing coke, being heated to redness, oil is allowed to drop on the coke by small quantities: the oil is decomposed; and gases, nearly similar to those obtained from coal, are produced. But, in a given volume of oil gas, there is much more

* The chaldron is generally estimated at 27 cwt. Mr. Lowe's statements show it to be about 25 cwt.

inflammable matter than in an equal volume of coal gas; and hence, in its combustion, a greater quantity of light is emitted. It is supposed that oil gas has about twice the illuminating power of coal gas. An imperial gallon of the very best whale oil will afford about 120 cubic feet of gas: but the average product does not exceed 80 or 90, owing to the bad quality of the oil commonly employed. Resin gas is manufactured in the same manner as oil gas, except that, instead of decomposing oil in the retorts, they use a liquid prepared by melting common amber-coloured resin with a kind of thin oil, which arises during the decomposition of the resin, and condenses in the pipes. This gas seems to have an illuminating power not much superior to good coal gas. Many houses are lighted with it; and it is at present used for portable gas-lights; it being found to lose less by the condensation of liquid hydrocarbon in it under the necessary pressure, than oil gas, beside being much cheaper.

Superolefiant gas. — Beside carburetted and bicarburetted hydrogen, a third gaseous compound is believed to exist, which is obtained during the decomposition of oil for producing an illuminating gas, but which is not procurable in a separate form. It has been named superolefiant gas. One volume requires, for complete combustion, according to Dr. Henry, 4½ volumes of oxygen gas, and affords 3 volumes of carbonic acid. From this it is easy to calculate its composition. If 3 volumes, suppose 300 cubic inches, of carbonic acid are formed; then 300 cubic inches of oxygen combined with (12·682 × 3 =) 38·046 grains of carbon, which was the whole quantity in the superolefiant gas. There remained 1½ volume, that is, 150 cubic inches, of oxygen to combine with the hydrogen, which, consequently, must have been twice as much, or 300 cubic inches, weighing (2·1197 × 3 =) 6·3591 grains, which, when added to the 38·046 grains of carbon, give 44·405 as the weight of the original 100 cubic inches of superolefiant gas. The specific gravity of superolefiant gas

is therefore 1·4412. The existence of this gas, as a distinct compound, has been questioned; it has been suggested, that it may be a mixture of carburetted hydrogen with some of the other hydrocarburetted products presently to be described. But superolefiant gas may be exposed to a degree of cold, without condensing into a liquid, which the other hydrocarburets cannot sustain, and continue in the gaseous state. This, connected with the facts already stated, seems to render it very probable, that superolefiant gas is a distinct compound. Its name is inappropriate.

The two compounds of carbon and hydrogen that remain to be described were discovered by Dr. Faraday, with some others which present less distinct results, in the oil gas which had been compressed into the recipients of Gordon's portable gas-lights. Compression of common oil gas to 30 atmosphere caused the deposition of a fluid, the specific gravity of which was but 0·821. Dr. Faraday found this to be a mixture of various bodies, separable from each other by their difference of volatility. By a complicated process, he obtained a bicarburet and a carburet of hydrogen. Bicarburet at common temperatures is a transparent, colourless liquid, having a mixed odour of oil gas and almonds: its specific gravity is 0·850: it crystallises, but the crystals fuse at 42°: at 0° it is white, transparent, and as hard as loaf sugar: it boils at 186°; burns with a bright flame, and much smoke: its vapour mixed with oxygen detonates powerfully. The other compound, which for the present may be called Faraday's carburet of hydrogen, is a liquid at 0°: it boils and evaporates at a temperature below 32°; the vapour may be recondensed by cold; it is therefore not a permanent gas. Its specific gravity, when kept liquid at 54° by pressure is 0·627: it is, therefore, the lightest body in nature. Its vapour burns readily, and with a brilliant flame.

One hundred cubic inches of the vapour of Faraday's bicarburet of hydrogen require 750 cubic inches of oxygen for their combustion, and the result is 600 of car-

bonic acid, and the due product of water. The carburet of hydrogen requires 600 of oxygen, and the resulting carbonic acid is 400 cubic inches. In the manner already shown, we may hence calculate the constitution of both, and the specific gravities of their vapour. Faraday's bicarburet must consist of 600 cubic inches of carbon vapour, and 300 of hydrogen condensed into 100 cubic inches; but the carburet is composed of 400 cubic inches of carbon vapour, and an equal volume of hydrogen condensed into 100 cubic inches.

Amongst the names of these five compounds there exists much confusion; and the necessity of reform in the existing nomenclature of the science is no where more conspicuous. The source of the perplexity in this case arises from a circumstance in the constitution of matter which has but lately come under the cognizance of chemists, and for which no provision was made by the framers of the nomenclature at present in use when their system was originally promulgated. It was formerly supposed, that when the ingredients of two compounds and their relative quantities are the same, the compounds themselves are the same. This view is now found to be incorrect. The elements and their ratio may be identical, yet the resulting compounds may be totally different in their properties. Of the truth of this position, perhaps, no better proof need be adduced than some of the hydrocarburets at present under consideration; although the relation of phosphoric and pyrophosphoric acids, that of acetic and succinic acids, and of the two kinds of tartaric and stannic acids, to each other, might be adduced. We have a gas which contains 200 volumes of carbon vapour, and 200 of hydrogen condensed into 100; another which contains 300 volumes of each condensed into 100; and a third, which, in 100 volumes, contains no less than 400 volumes of each.

In these cases the ratio of the ingredients, which is the circumstance that determines the prefix of a name, cannot be made the basis of a distinctive appellation, it being the same in all. They should, so far as the prefixes

in use are concerned, have the same name, because they are varieties of the same thing. How, then, are they to be distinguished? In the class of substances alluded to above, such as phosphoric, stannic, and tartaric acids, Berzelius prefixes the Greek preposition παρα, to the compound less easily obtained; thus paraphosphoric, parastannic, paratartaric acids. But these prefixes do not seem to apply to the cases under consideration. As some distinction must be made, I shall here adopt one that is not founded upon any consideration of the number of atoms which constitute an integrant particle—for on this subject all our information is uncertain; but on the fact that the three varieties of carburet of hydrogen differ in the condensation of their constituent volumes. The first (200 volumes + 200 = 100) shall be simply called carburet of hydrogen; the second, being composed of $1\frac{1}{2}$ times the volume of the former (300 + 300 = 100), will be sescuplocarburet of hydrogen; and the third, containing intrinsically double the volume of the first (400 + 400 = 100), will be duplocarburet.*

It remains to decide on the names of the other two compounds. The old *marsh gas* consists, as will be explained hereafter, of two atoms of hydrogen combined with one atom of carbon: it may therefore be called bihydruret of carbon. On the other hand, the compound discovered by Dr. Faraday consists of two atoms of carbon

* The words *sescuplum* and *duplum*, as every one knows, are derived from *plica*, a fold, compounded with *sesqui* and *duo*: hence, in the present instances, they form adequate prefixes. Sescuplocarburet means "one and a half-fold carburet," which just applies to the condensation of $1\frac{1}{2}$ volume of the simple carburet in to one volume of the sescuplocarburet. Duplocarburet, meaning "two-fold carburet," exactly designates the two-fold condensation of the carburet into this gas. Sescuplo answers better than sesquiplo, as chemists already use *sesqui*, but for a different purpose.

The prefix *bis* or *dis* is useful for expressing the repetition of the atom of matter that is indicated by the part of the name to which the prefix is attached: but I think the effect of the prefix so attached should not extend to the matter represented by the other part of the name. For instance, the name *disulphate of alumina*, at present given to the compound of 1 atom of sulphuric acid and 2 atoms of alumina, might seem to convey that 2 atoms of sulphuric acid are combined with the base. By inverting the order of the generic and specific members of the name, the Greek or Latin numerical adverb may be prefixed without fear of misconception. In this way I have used the names bihydruret of carbon and bicarburet of hydrogen,—terms generally acknowledged.

combined with one of hydrogen: he called it bicarburet of hydrogen,—a name sufficiently expressive, and analogous with the former.

We have, therefore, certain evidence of the three following distinct hydrocarburets: 1st, bihydruret of carbon; 2d, carburet of hydrogen, of which there are three varieties; 3d, bicarburet of hydrogen. With regard to the second compound and its varieties there can be no confusion, for two of them are distinguished by prefixes peculiar to them; and when the name carburet of hydrogen is used without a prefix, it means that one which is unity with regard to the others in point of condensation. In the carburet of hydrogen there is no predominance of either ingredient; they exist atom to atom, as will be explained hereafter; and this condition seems best expressed by a name without a prefix.

Table of the chief Compounds of Carbon and Hydrogen.

100 cubic inches of	Consist of — In grains		Consist of — In cubic inches.		Weight of 100 cubic inches in grains	Specific gravity of the gas or vapour.	Grains weight of carbon, combined with 100 grs. of hyd.
	Carbon.	Hydr.	Carbon vapour.	Hydr. gas.			
1. Bihydruret of carbon (marsh gas)	12·682	4·239	100	200	16·9214	0·5492	29·9146
2. Carburet of hydrogen 1 (olefiant gas) -	25·364	4·239	200	200	29·6034	0·9608	59.8293
Sescuplo-carburet 2 (superolefiant gas)	38·046	6·359	300	300	44·4051	1·4412	52·8293
Duplocarburet 3 -	50·728	8·479	400	400	59·2068	1·9216	59·8293
3. Bicarburet of hydrogen (vapour) -	76·092	6·359	600	300	82·4511	2·6759	119·6587

It might appear to the student, that, as the three varieties of carburet of hydrogen differ only in density, it would be possible to bring them all to the same con-

stitution by mechanical rarefaction or compression. But this is not so; for they would return to their former volume on the removal of the restraint.

The compounds of carbon and hydrogen correspond with the law of multiple combination already explained in the chapter on affinity: the last column of the table shows the series of numbers representing the quantity of carbon which a certain quantity of hydrogen combines with. This series, when reduced to its lowest terms, is 1, 2, 4. There are other hydrocarburets known, of which the chief are naphtha and naphthaline, both obtained from coal tar by distillation: the former is a transparent, colourless, volatile liquid; the latter is a transparent, colourless, volatile solid, which assumes the form of crystalline plates.

Cyanogen.—When charcoal and ammonia are heated in contact, a compound is produced of very singular properties. Ammonia is composed of hydrogen and azote: the compounds of charcoal with hydrogen possess no such properties as those noticed by Scheele; consequently, they must be attributed to the formation of a combination of charcoal with azote. When a combination is effected between azote and carbon, no matter by what means, a gas is produced which resembles common air, so far as elasticity and transparency are concerned, although by mechanical pressure it is condensed into a liquid. 100 cubic inches of this gas weigh 55·3996 grains, hence its specific gravity is 1·798. Water absorbs about 4½ times its bulk of it. It kindles at the flame of a candle, and burns with a beautiful bluish purple light. When 100 cubic inches are exploded by an electric spark, along with 200 cubic inches of oxygen, the result is 200 inches of carbonic acid, and 100 of azote. Hence this gas consists of 100 cubic inches, that is, its own bulk of azote, holding twice 12·682 grains of carbon dissolved, or 100 cubic inches of azote combined with 200 of carbon vapour: but it contains no hydrogen, as appears from the fact of its not producing a particle of water when burnt with oxy-

gen. The method of preparing this gas will be presently given.

The brilliant pigment, called Prussian blue, owes its colour, as will be shown hereafter, to the presence of the gas under consideration. On account of its property of generating this blue colour, this gas has been called *cyanogen*.

Hydrocyanic acid.—Cyanogen gas has the property of combining with both hydrogen and oxygen, and forming acids. If we combine equal volumes of cyanogen and hydrogen, two volumes will result of a compound which reddens vegetable blues, and possesses the other properties of an acid. This acid is still in the state of gas; but it is readily absorbable by water or alcohol. Being composed of hydrogen and cyanogen, it has obtained a name indicative of its origin, and is called *hydrocyanic acid:* it has been for some time used as a medicine: it is capable of acting as an immediate and virulent poison, whether it be breathed in the gaseous form, or swallowed, or rubbed to the body in its liquid form, that is, condensed by cold or in water. It was formerly called Prussic acid, from being an ingredient in Prussian blue.

It may be prepared by boiling a mixture of 6 ounces of Prussian blue in powder, with 5 ounces of red precipitate (i. e. peroxide of mercury), and 40 ounces of water, for half an hour, then straining through paper, and boiling away some of the water in a glass vessel. On cooling, the liquor will deposit crystals which are a compound of cyanogen gas and mercury, called cyanuret * of mercury. From this salt we may prepare either cyanogen gas or hydrocyanic acid. If, after being perfectly dried, it be distilled in a retort by heat, cyanogen gas will come over, which is to be collected in a pneumatic trough filled with mercury, as it is absorbed by less than one quarter its volume of water. Or if the salt be distilled in a retort with seven eighths of its weight of muriatic acid, specific gravity 1·16, we obtain hydrocyanic acid in vapour, which may be con-

* Cyanurets are otherwise called cyanides, or cyanodides.

densed by cooling the receiver with snow. This liquid contains a little muriatic acid and water, both of which can be removed by a second distillation from well-dried chalk.

Liquid hydrocyanic acid has a most agreeable smell, which is easily recognised in certain flowers — the wall-flower, for instance — and in the blossoms of various trees, as the peach tree and hawthorn: this acid seems, indeed, to be their odoriferous principle. It is found in various kernels, as those of the apricot, cherry, and almond; in the last, in such quantity as to have occasioned death. It exists in the leaves of the common laurel so largely, that a water distilled from them is almost an instantaneous poison. This fact was discovered in 1728, at Dublin, where several persons who had used it as a cordial, mixed with spirituous liquors, were poisoned; and investigations were undertaken by Drs. Madden, Mortimer, and Rutty, to prove its virulence. Taken in very small doses, hydrocyanic acid retards the velocity of the circulation.

Liquid hydrocyanic acid, which contains no water, is exceedingly volatile; it boils at 80°, it freezes at 5°; if allowed to evaporate spontaneously, it produces such cold as to freeze itself. By keeping, it in a very short time suffers spontaneous decomposition and spoils, especially if it contain muriatic acid: the more concentrated it is, the more speedily it suffers. When pure, its specific gravity at 64° is 0·697. If much diluted with water, and secluded from the action of light, it may be preserved unaltered for a great length of time. Its vapour is inflammable.

Cyanic acid.—When cyanogen is combined with oxygen instead of hydrogen, *cyanic* acid is obtained. It is composed of 100 parts of cyanogen combined with 30·769 of oxygen; hence, 100 parts of cyanic acid consist of carbon 35·3, oxygen 23·53, and azote 41·17.* By the process which affords it, it is obtained in a state

* Centesimal ratios greatly facilitate calculation: hence I retain them, although they are going out of use.

of dilution with water; and if kept in this state for a few hours, it is decomposed, as well as some of the water: the hydrogen of the latter and the azote of the former combine and produce ammonia; and the carbon combines with the oxygen of both the acid and water, forming carbonic acid, which enters into combination with the ammonia. If the compound of this acid with potash be boiled with water, a decomposition takes place, and a compound of carbonic acid and potash results, ammonia being extricated. The taste of cyanic acid is sour; it reddens vegetable blues; its smell somewhat resembles that of acetic acid.

Fulminic acid.—There is another compound of cyanogen, of an acid nature, which enters very extensively into combination with bases; and most of the compounds which result have the remarkable property of producing a loud explosion, accompanied by the emission of heat and light, when they are heated, rubbed, or struck. The loudness of the noise has obtained for the acid the name of *fulminic* acid. According to Gay-Lussac and Liebeg, the fulminic and cyanic acids consist of the same elements, and in the same ratio, although the properties of the two acids are totally different. Were this well founded, it would afford another instance of the truth of the statement, that identity of elements and relative quantity does not constitute identity of constitution. But according to professor Davy, of the Royal Dublin Society, who has been the most extensive enquirer into this subject, fulminic acid differs from cyanic, not only in the ratio of its elements, but in containing an additional element—hydrogen.

The substance from which this singular acid is prepared is the powder called Howard's fulminating mercury. To obtain the latter, dissolve 100 grains of mercury in a measured ounce and a half of nitric acid (specific gravity 1·3) by heat. Pour the solution, when cold, on 2 ounces' measure of alcohol (specific gravity 0·849) in a glass vessel, and apply a moderate heat till an effervescence be excited. A powder gradually pre-

cipitates, which is to be immediately collected on a filter, well washed with distilled water, and dried at a heat not exceeding that of boiling water. These are Mr. Howard's directions: the product he obtained, varied from 120 to 132 grains. It is not necessary to observe the above specific gravities very exactly: I succeeded with acid of 1·4, and alcohol of 0·840; and my product weighed 113 grains. It is by no means a perishable compound: I have a specimen prepared about twelve years since, which is now as violent as ever. When a grain weight of fulminating mercury is struck on an anvil with a small hammer, a sharp, stunning detonation is produced, accompanied by a flash; a little whitish smoke is extensively diffused, which occasions sneezing. A drop of sulphuric acid let fall on the powder causes it to burn off in a blaze, without explosion. It is a curious fact, that this blaze does not burn gunpowder. Fulminating mercury is composed of fulminic acid united to red oxide of mercury. The acid may be transferred to other bases by double decomposition. Its compounds all possess the property of fulminating when rubbed or smartly struck. Fulminating silver may be prepared by the same process as fulminating mercury; it is a highly dangerous substance, and has been the cause of loss of life, and of many accidents. Fulminating gold was formerly in use as a medicine.

Cyanuric acid. — Besides these combinations of cyanogen, there is another, which contains double the quantity of oxygen that exists in cyanic acid. It also contains hydrogen. It is called cyanuric acid, — a name peculiarly unfortunate, as its salts must be called *cyanurates*, which, in utterance, is not easily distinguishable from *cyanurets*. Cyanuric acid is a crystallisable substance. 100 parts of it consist of cyanogen 60·465, oxygen 37·209, and hydrogen 2·326.

Ferrocyanic acid. — Cyanogen enters into combination with both hydrogen and metallic iron, and forms an acid, hence named *ferrocyanic* or *hydroferrocyanic acid.* In this compound, 72·22 grains of cyanogen, 25·93 of

iron, and 1·85 of hydrogen, are combined to form 100. It is of a pale yellow colour; is less perishable than hydrocyanic acid; but exposure to light or heat decomposes it into hydrocyanic acid and a white precipitate, which, when it absorbs oxygen from the air, becomes Prussian blue. It reddens vegetable blues, and expels the carbonic and acetic acids from carbonates and acetates. Reagents or tests do not discover the presence of iron in this acid, because it is not oxidated; but when some of its combinations are heated strongly, its iron is oxidated, and oxide of iron is evolved. Prussian blue consists of this acid, combined with peroxide of iron; at least, this is the nature of its colouring matter; and it is diluted, and rendered a colour of body by means of an admixture of alumina.

There are three opinions concerning the manner in which the elements of this acid are combined. Some consider the cyanogen, iron, and hydrogen, as combined together, without being coupled in any manner with reference to each other: some conceive that an acidifiable base, consisting of cyanogen and iron, is acidified by hydrogen; an opinion which does not differ much from the former: others suppose that the cyanogen and iron, combined as a cyanuret, are dissolved in hydrocyanic acid. An experiment was made by Mr. Porrett, from which inferences may be drawn that seem calculated to establish the first or second opinion. By placing ferrocyanate of soda in the galvanic circuit, the soda passed to the negative pole, and the elements of ferrocyanic acid passed to the positive. These elements are iron, hydrogen, and cyanogen. Had the iron been in the state of oxide, as it was formerly supposed to be, it would have been found at the negative side, as happens with metallic oxides. But it may be objected, that being in the metallic state, it should have been found there equally; and this would certainly have been the case, were it not that it was held united to the other elements by an affinity so powerful that the galvanic order of arrangement was subverted. The same subver-

sion of the galvanic order is observable in the case of metallic oxides, earths, and alkalies. All these contain oxygen, which, when separate, collects at the positive pole; but when combined with a metal, goes along with the latter to the negative pole, because of the powerful affinity which antagonises its natural tendency. The question now occurs, what were the other elements of the hydrocyanic acid which held the iron by so forcible an affinity? Those who maintain the opinion that this acid consists of cyanuret of iron, merely dissolved in hydrocyanic acid, would answer, that the iron and cyanogen thus powerfully attracted each other; and that the fact so far corresponds with their view, as the cyanogen would naturally pass to the positive pole. It must, however, be recollected, that the validity of this answer is negatived by the passage of hydrogen to the positive pole, contrarily to its natural tendency; and the position is not tenable that it was carried over by the affinity of cyanogen — for so weak is that affinity known to be, that cyanogen and hydrogen will not subsist in combination sometimes for more than a few hours. The conclusion seems inevitable, that ferrocyanic acid does not consist of cyanuret of iron *dissolved* in hydrocyanic acid; but that it consists of iron, carbon, azote, and hydrogen (not adverting to whether the three first constitute a base acidified by the last), all held by an affinity capable of resisting the decomposing energy of galvanism. Hence the greater permanence of this acid than that of hydrocyanic acid; yet by the agency of water and light it is at length decomposed. It is true, that in Mr. Porrett's experiment some hydrocyanic acid was volatilised, and some Prussian blue was formed; but this was because the iron, on arriving at the platinum wire of the positive pole, was oxidated by the water in the same manner as the wire would have been were it iron, or as the platinum itself would have been had it been in nitric acid, and the galvanic battery very powerful. But for the interposition of the galvanic agency on the iron, there would probably have been no

decomposition. The oxide of iron joined the remaining ferrocyanic acid."

The quantities of carbon and azote in ferrocyanic acid are in the ratio necessary to the formation of cyanogen; the hydrogen is only in such quantity as to convert two-thirds of the cyanogen into hydrocyanic acid; the remaining third of cyanogen is sufficient to convert the iron into cyanuret. The object of these observations will appear, when we come to consider the combination of hydrogen acids with bases.

That a metal should constitute an element in a base which, with hydrogen, forms an acid, will be the less surprising, when it is considered, that the metal tellurium, by itself, is actually an acidifiable base with regard to hydrogen.

SECTION V.

CHLORINE.

Chlorine, as already stated, is a gas of a greenish colour. It may be prepared by mixing common sea salt with three quarters its weight of black oxide of manganese, introducing them into a retort, and pouring on sulphuric acid equal to the weight of the salt, and diluted with its own weight of water. The acid mixture should be added at two or three different times, the gas produced by the first quantity being collected before the second acid is poured on: this precaution is to guard against too violent an effervescence; and on the same account no heat should be applied until the effervescence becomes very moderate. After the common air has been expelled, the gas may be collected in bottles filled with water, and inverted in as little water as will answer the purpose, in order to prevent waste by absorption. The bottles, or pneumatic trough, must not be filled with mercury, as this metal is powerfully acted upon by chlorine.

Chlorine, if breathed undiluted, is fatal to animal life, but does not extinguish combustion. A candle burns in it with a red flame. It possesses the remarkable property of setting fire to many of the metals, even at the common temperature of the air, when introduced into it, beaten out into thin leaves or reduced to filings; such are copper, tin, arsenic, zinc, and antimony. Phosphorus, when introduced into it, burns with a pale white light. Mercury absorbs it rapidly. Water absorbs twice its bulk of it: the solution is called chlorine water; and if this be exposed to light, some water is decomposed, its oxygen is liberated, and the hydrogen combines with the chlorine, forming muriatic acid. As the combinations of metals with oxygen are called oxides, so the combinations of metals with chlorine are called *chlorides*.

Chlorine has the property of destroying all vegetable colours. If a vegetable blue, for instance, be exposed to its action, the colour is not altered to red, as it would be by an acid, - nor to green, as it would be by an alkali, — but it is totally destroyed; and the medium, in the substance of which the blue was contained, appears colourless, at least so far as the vegetable was concerned. On this account, chlorine has been introduced as a powerful agent in the art of bleaching; for if unbleached linens be properly exposed to its action, the matter which gives them their gray colour is destroyed, and the linen assumes the whiteness which is natural to its fibre. Flax is naturally white, and owes the gray colour which it assumes solely to the processes through which it is put to separate its fibres — as immersion in bog streams, and other such injurious treatment. The chlorine, however, if applied in its pure state, and not sufficiently diluted, or otherwise corrected, invariably destroys the strength and texture of the linen; and, therefore, it is a dangerous agent in the hands of the inexperienced.

The specific gravity of chlorine gas, when quite free from watery vapour, is, according to Thomson, 2·5:

100 cubic inches of it, therefore, weigh 77·0287 grains When perfectly dry, it remains a gas at the temperature of — 40° ; by means of mechanical pressure, it may be condensed into a yellow liquor; in which state it remains only while the pressure continues. When saturated with watery vapour, or dissolved in water, and exposed to a cold of 32°, it forms into crystals, which consist of 72·3 of water combined with 27·7 of dry chlorine. This compound is called *hydrate* of chlorine.

Chlorine has an affinity for oxygen, and they combine in no less than four proportions: two of them contain so much oxygen as to form acids; and the other two, as they do not manifest any acid properties, are to be considered as oxides. Oxygen and chlorine, notwithstanding their affinity, do not combine when presented to each other; but they may be detached in combination from certain compounds which contain them.

Protoxide of chlorine. — When 100 parts of chlorine combine with 22·219 of oxygen, a gas is produced, which, as it is the combination containing the least oxygen, is called *protoxide of chlorine.* It has a smell resembling burnt sugar. It was discovered by sir H. Davy; and was named by him *euchlorine,* in consequence of its very green colour. Under strong pressure, this gas is condensed into a liquid. When warmed in a glass tube, even with the heat of the hand, it explodes, and expands into a greater bulk, the increase being $\frac{1}{5}$th of the whole; a flash of light is at the same time produced; and the tube is now found to contain a mixture of oxygen and chlorine, no longer in combination. Combustibles first decompose euchlorine, and then burn. It reddens vegetable blues, and then destroys the colour totally.

Peroxide of chlorine. —When 100 parts of chlorine are combined with four times the quantity of oxygen which enters into the protoxide, that is, with 88·876 of oxygen, the compound formed is the peroxide. It, as well as the protoxide, may be collected over mercury,—

that metal being not affected by either gas; but both of them are absorbed by water. The colour of this gas is an intense and lively yellow. It discharges vegetable colours, like chlorine. When heated, it explodes with a considerable emission of light; and 2 volumes expand into 3: these 3 volumes are a mixture of 2 volumes of oxygen and 1 of chlorine; the gases being no longer in combination. Phosphorus, immersed in it, causes an explosion by decomposing it; oxygen and chlorine result, and the phosphorus burns in the mixture. Peroxide of chlorine may be formed by thoroughly mixing a small quantity of the salt sold by druggists under the name of *chlorate* or *oxymuriate of potash*, with as much sulphuric acid as will form a paste, and exposing the mixture to a very gentle heat, in a very small retort: small quantities should be employed, lest explosion should take place. The same salt, when heated with dilute muriatic acid, affords protoxide.

Chloric acid.—When 100 parts of chlorine combine with five times as much oxygen as exists in the protoxide, that is, with 111·095 parts of oxygen, an acid is produced, which is called *chloric acid.* It was formerly named *hyperoxymuriatic acid.* Water is necessary to its constitution; and, hence, it is always obtained in the state of a solution in water, which has an acid and astringent taste, but no smell: it reddens vegetable blues,—the characteristic power of chlorine on vegetable colours being subdued; the colour, however, is at length destroyed.

Perchloric acid.—The last compound of chlorine and oxygen is formed when the quantity of the latter is seven times greater than exists in the protoxide; or, when 100 parts of chlorine combine with 155·533 of oxygen. In this case a distinct acid is formed, called *perchloric acid,* the properties of which have not been ascertained.

Thus chlorine, by uniting to different portions of oxygen, forms four different compounds. The elements in all of them are retained by a very feeble affinity;

hence the facility with which oxygen is transferred from them, and the brilliant phenomena which often occur during the transfer. If we reduce the numbers representing the different quantities of oxygen, viz. 22·219, 88·876, 111·095, 155·533 to their lowest terms; then the oxygen of the protoxide will be 1, of the peroxide 4, that of chloric acid 5, and that of perchloric acid 7; all these numbers being in conformity with the doctrine of multiple ratios. It is probable that other compounds will yet be discovered.

Muriatic or *Hydrochloric acid.* — Besides uniting with oxygen, chlorine combines with hydrogen, and forms muriatic acid. If chlorine and hydrogen be mixed together in equal volumes, and exposed to common daylight in a glass flask, they will, in a little time, combine; and even explode in combining, if they had been exposed to sunlight, or to the action of an electric spark, or to the light of a candle. Two volumes of muriatic gas result. Besides this synthetical proof, the composition can be shown analytically.

Muriatic acid gas, in its pure state, is transparent, colourless, and elastic: under very strong pressure, it condenses into a liquid. A volume of chlorine and a volume of hydrogen combine and form two volumes of muriatic acid gas: hence, as there is no change of bulk by condensation, we can find the specific gravity of muriatic acid by adding together the specific gravity of each constituent, and taking half the sum as the specific gravity of the compound. The specific gravity of hydrogen is 0·06879, that of chlorine 2·5: the sum is 2·5688, and the half is 1·2844, which is the specific gravity of muriatic acid gas, and is identical with the result of an experiment made by Thomson. Water absorbs this gas with avidity; one cubic inch at 69° absorbs 417·822 cubic inches of the gas; heat is produced, and, when cold, the bulk of the water is increased to 1·3433 cubic inch. This is liquid muriatic acid: with these proportions of constituents, its specific gravity is 1·1958: 100 grains of it consist of 40·39 of

real acid and 59·61 of water.—(*Thomson.*) But at 40°, water is capable of combining with 480 times its bulk of the gas. The specific gravity of the strongest liquid acid that can be conveniently obtained is 1·203. In this state it is very volatile; it boils at 107°, and frequently forces the stopper out of the bottle in warm weather. At a temperature below freezing, acid may be obtained so strong as 1·500; but as the temperature rises, the liquid gives off acid fumes, which leave the remainder weaker, until, at 60°, it becomes 1·203. It is a colourless liquid; and, when exposed to the air, it smokes, because the gas exhaled condenses the moisture of the atmosphere. It extinguishes both flame and life, and is not inflammable. Its smell is pungent, suffocating, and somewhat aromatic. It powerfully reddens vegetable blues.

The method of preparing muriatic acid, just now described, is not that employed for preparing it for use. Common culinary salt is the source from which it is derived. A mixture of this salt with sulphuric acid and water is to be distilled with a heat barely sufficient: a yellow liquid acid comes over; but if the salt had been previously heated nearly red-hot, the acid is almost colourless. According to Dr. Barker, of Dublin, who made many experiments on the subject, equal weights of salt and sulphuric acid give the largest product. With 5000 grains of salt, the same of the strongest sulphuric acid, and 8000 grains of water, the product was 9389 grains of muriatic acid, specific gravity 1·160.*

Chloride of azote. — There is but one known combination of chlorine with azote: it is one of the most formidable and dangerous substances in nature, owing to the facility with which it explodes, and the violence of the explosion. It is called chloride of azote. Pour upon a flat dish a warm and unsaturated solution of sal ammoniac in water. Fill a phial bottle with

* See his "Observations on the Dublin Pharmacopœia," page 36.; a very useful commentary.

chlorine, and cork it: then invert the bottle in the solution, and uncork it under its surface. An absorption of the gas takes place; it decomposes the ammonia, combines with its azote, and forms a yellowish oily substance, which is chloride of azote. When one or two globules are formed, the process should be stopped on account of the danger. If heated to 212°, this chloride is resolved into its elements with a tremendous explosion. Contact with phosphorus, oils, and a variety of substances, cause the same effect. It consists of 4 volumes of chlorine, combined with 1 of azote. Its colour is pale greenish yellow. It boils at 160°: no known cold is capable of freezing it. Its consistence is little more than that of water. It is soon decomposed when left in contact with water. Its specific gravity is 1·653.

Perchloride of carbon.—By the action of chlorine on olefiant gas, a compound of chlorine and carbon is formed, called perchloride of carbon. When heated in a retort, it evaporates, and the vapour condenses into crystals. If sublimed rapidly at a high heat, it forms a transparent, colourless mass. It burns in the flame of a candle with a red light and much flame. It has a smell somewhat resembling camphor; like camphor it scarcely dissolves in water, but easily in alcohol, from which it is precipitated by the affusion of water. Hot alcohol dissolves more than cold; and a hot solution affords crystals on cooling: the same may be said of ether. It dissolves also in oils. Camphor, included in a bottle, volatilises and crystallises on that side of the bottle most exposed to the light; this chloride does the same; and the other points of resemblance to camphor are striking.

If this perchloride of carbon be passed in vapour through a red-hot glass tube, a part of the chlorine is given off, and a *protochloride* is produced, which may be condensed in a cool part of the tube. This is a liquid which does not seem to possess any very striking properties.

It has been observed by Dr. Silliman, that if, in attempting to mix chlorine with olefiant gas, the latter be allowed to occupy the upper part of the vessel, and the former the under part, a bright flash and slight explosion will take place; carbon will be deposited, and the chlorine will disappear.

Chlorocarbonic acid. — There is a gaseous combination known in which carbon is acidified by both oxygen and chlorine. It is called chlorocarbonic acid. It is produced by exposing equal volumes of perfectly dry chlorine and carbonic oxide in a glass flask to strong sunshine. They combine and condense to one volume. This is an acid; for it reddens litmus, and combines with certain alkalies. It has an exceedingly pungent smell. Water decomposes it.

Section VI.

There exists a substance much resembling chlorine in some of its properties, and derived from a source which also supplies chlorine: they are both of marine origin; the latter existing in sea water, and the former chiefly in sea plants. This substance may be procured by drying and powdering common sea weed, and heating it with sulphuric acid: a violet coloured vapour rises, which, if received in a cool vessel, will condense on its sides, and will form scaly crystals, of a somewhat metallic lustre. These crystals are the substance in question; from the violet colour of its vapour, it is called *iodine*. When exposed to the air at common temperatures, it volatilises slowly but completely; but in close vessels it requires the application of heat for evaporation. At a heat a little above that of boiling water, it melts; at 350°, it boils and evaporates in a violet coloured vapour, almost exactly the colour of the vapour discharged from indigo thrown on hot iron; it crystallises as it cools. The specific gravity of iodine is, ac-

cording to Dr. Thompson, 3·084. It has a leaden gray metallic lustre, but it is a non-conductor of electricity. It has resisted all efforts to decompose it, and may be passed in vapour through a red-hot earthen tube without change. It has the property of forming a beautiful blue colour, when mixed with a little powdered starch diffused through cold water: and hence iodine and starch are used by chemists as mutual tests of each other's presence even in the most minute quantity. Iodine stains the fingers yellow, and consumes the cork of the phial in which it is contained. It dissolves in 7000 times its weight of water, and the solution is brownish yellow; but it is by far more soluble in alcohol or ether; and the tincture, if concentrated, is of a deep reddish brown. It has a smell of chlorine: like chlorine, it destroys vegetable colours; and, like that substance, it combines with oxygen or hydrogen—in either case forming an acid. With chlorine it also forms an acid, which is called chloriodic acid.

The process given above for obtaining iodine, is not the one by which it is procured for sale: and it can be now purchased at so low a price, that no chemist ever thinks of preparing it for his own use. Dr. Ure has given the process in full detail: it is one invented by himself; the following is an outline:—

Iodine is largely contained in *kelp* *; and it may be economically prepared from the brown oily-looking liquor which is the waste of the soap manufacture, and in which all the iodine originally contained in the kelp used in that manufacture is to be found.

Every 8 ounces, apothecaries' measure, are to be mixed hot with 1 ounce measure of sulphuric acid diluted with its bulk of water. When cold, filter the liquor; add 666 grains of black oxide of manganese; and introduce the whole into a large glass globe, over the wide neck of which another is to be inverted and kept cool, while the bottom of the lower one is heated

* The semifused ashes of sea weed.

by burning charcoal to about 232°. Iodine now sublimes copiously, and is readily condensed in the upper vessel. From the above quantities, about 1 drachm troy will be obtained.

Iodine combines with sulphur, although without much force of affinity; with phosphorus it combines energetically; it unites with carbon, and with various metals; but in none of these combinations is there much interest. It is a poison; but in minute doses it is used in medicine, and, if long continued, produces remarkable emaciation.

Oxide of iodine, and *Iodous acid*. — There are three combinations of iodine and oxygen known, — oxide of iodine, iodous acid, and iodic acid; the two first were discovered by professor Sementini, and the following is the process for obtaining it, as described by himself: — "A copper tube, two spans in length and eight lines in diameter, is furnished at one end with a screw, its other end terminating with an aperture one line in diameter. This extremity must be bent in such a way as to be introduced into the tubulature of a retort, leaving the latter a proper inclination. A bladder of oxygen must be screwed into the other end of the tube. Along and underneath the tube, a long spirit lamp should be placed, furnished with several wicks, which, when kindled, are capable of heating it to redness. At the same time a lamp must be placed under the retort. When the retort and tube are both nearly red-hot, one assistant strongly compresses the bladder, while another introduces a spoonful of iodine into the beak of the retort; and this, falling under the copper tube from which the hot oxygen issues with force, is reduced to a violet vapour, which gradually disappears, lining the beak of the retort with a yellow, transparent matter, almost solid. This is the *oxide of iodine;* it has the consistence of a solid oil; its taste is rough and disgusting; it evaporates totally in the air; it is very soluble in alcohol and water, and communicates an amber yellow, which alkalies render colourless: brought in contact

with phosphorus, the latter inflames." He further found, that "by continuing the jet of oxygen after the beak of the retort becomes lined with the yellow, soft-solid oxide, iodous acid will begin to form, which will run down along the beak, and will announce itself sufficiently by the redness which it occasions in tincture of turnsole. The production of iodous acid will be facilitated, if, while the jet of oxygen is continued, the lamp, instead of heating the belly of the retort, is employed to heat the oxide in the beak, which, immediately combining with a new portion of oxygen, is converted into iodous acid." * Sémentini has also shown, that by mixing iodine with chlorate of potash, both in powder, and in such proportions as will produce a yellowish colour (three parts of chlorate of potash and one of iodine succeed best), and applying a gentle heat, an amber-coloured liquor distils over, evaporable at so low a heat as 112°; of a strongly acrid and disagreeable odour; capable of reddening without destroying vegetable blues, and of inflaming phosphorus. This also is iodous acid. In order to produce it, a gentle heat must be applied. A strong heat will altogether change the nature of the products.† The acid will more certainly be obtained pure, if three parts of chlorate of potash to one of iodine be employed.

Iodic acid.—By exposing iodine to the action of protoxide of chlorine, the latter is decomposed; its two elements combine with iodine; and two compounds are formed, named chloride of iodine and iodic acid. As these substances differ in volatility, the application of heat drives off the former, and iodic acid remains. It is a solid, semi-transparent, white substance, not only soluble in water, but deliquescent. It first reddens and then destroys vegetable blues. When heated strongly by itself, it is resolved into its elements; but if heated with combustible bodies, an explosion takes place.

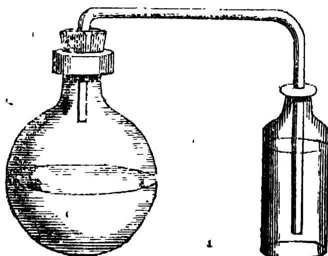
Chloride of iodine may be prepared also by exposing

* Giornale di Fisica, 1826, 387. † Ibid. 1825, 157.

iodine to chloride: the latter is absorbed, and a chloride is produced which manifests the properties of an acid; but it is uncertain whether in its own nature it is an acid, or whether it becomes one only when, by decomposing water, its elements are acidified. Those who consider it an acid in its own nature, have given it the name of *chloriodic acid*. At ordinary temperatures, it is a deliquescent solid; if heated, it melts into an orange liquid; and if still further heated, becomes an orange yellow vapour.

Hydriodic acid. — The combination of iodine with hydrogen possesses properties which eminently characterise it as an acid: its taste is acid, it reddens vegetable blues, and it combines with bases. The name of this compound indicates the two elements which form it; it is called hydriodic acid. It may be procured by the direct union of its component ingredients: if the vapour of iodine be passed through a red-hot tube along with hydrogen, both substances combine, and a colourless gas results, which is the acid in question. This gas, when allowed to escape into the air, condenses the moisture of the air, and thus produces abundant white fumes. It is decomposed by almost all metals; the iodine combining with the metal, and hydrogen being left uncombined. The same decomposition is effected by heating a mixture of it and oxygen or chlorine; water being produced in the former case, and muriatic acid in the latter, by the abstraction of the hydrogen, while the iodine is liberated. Hydriodic acid gas may be obtained by the action of iodine on sulphuretted hydrogen; the iodine takes the place of the sulphur; and on this fact is founded a good process for obtaining liquid hydriodic acid, which is as follows: — Triturate iodine and a a small quantity of water; when the mixture is tolerably smooth, add more water, and pass a stream of sulphuretted hydrogen gas through it, arising from a mixture of sulphuret of antimony and muriatic acid heated in a flask. The gas may be transmitted through the iodine and water by means of a glass tube bent twice at

right angles, as in the sketch, — a very easily constructed apparatus, which answers for all such purposes. The sulphuretted hydrogen is decomposed; the sulphur is



almost completely separated; the hydrogen, combining with the iodine, dissolves it, and forms liquid hydriodic acid, which may be filtered from the sulphur, and boiled for a few moments, to expel any redundant sulphuretted hydrogen. This liquor, when distilled, at first gives off water only, but at length the acid itself distils over. Hydriodic acid gas is absorbed copiously by water, and the result is liquid hydriodic acid. This liquid, by exposure to air, is speedily decomposed. 100 cubic inches of hydriodic acid gas contain 50 cubic inches of hydrogen, combined with 50 of the vapour of iodine. This gas is set on fire by pouring into the vessel which contains it a few drops of strong nitric acid.

Iodide of azote. — With azote, iodine combines, although indirectly, and forms a curious detonating compound. If liquid ammonia be poured on iodine, part of the ammonia is decomposed into hydrogen and azote: both of these combine with iodine; the former producing hydriodic acid, which unites to the remainder of the ammonia, and the latter affording the compound in question; to this the name of iodide of azote has been given. It is a dark brown powder, and is of so explosive a nature, that not only heating, but touching it, will cause it to detonate violently; and sometimes it

will detonate without any apparent cause. The results of the explosion are iodine in violet-coloured vapour, and azote; and the cause of the explosion is the concussion on the air, occasioned by the sudden conversion of these two substances from the solid to the gaseous state.

Iodine combines with several other substances, but the compounds need not be here noticed.

Section VII.

BROMINE.

This is a substance which resembles chlorine and iodine in many of their habitudes. If a large quantity of sea water be boiled down, and the common salt removed until it no more freely crystallises, we obtain a residual liquor, called by salt makers *bittern;* and an abundance of it can be procured at the salt works, often without charge, for in many localities bittern is made no use of. Through this liquid, chlorine gas is transmitted, until it assume a brownish yellow colour. Some ether being added, the whole must be well shaken, and then allowed to settle: the ether, now of a fine red hue, floats on the top, and, being decanted, must be shaken with pure potash, and dissolved in a little water. The ether now loses its colour, because it has transferred to the potash the matter which caused the colour. The same ether may be agitated with more bittern, which has been treated with chlorine, and may thus be made the medium of transfer between a large quantity of bittern and a small quantity of potash. The solution of potash, continually agitated with fresh portions of ethereal liquor, becomes so highly charged at length, that by being a little evaporated it will afford cubical crystals in abundance. If these be distilled in a retort with dilute sulphuric acid and some black oxide of manganese, red vapours will arise, which may be condensed into a very deep reddish brown liquor, by

receiving them in a globe or flask surrounded by ice or very cold water. This liquid is about three times as heavy as water (2·96): it is sparingly dissolved by water, more copiously by ether. At 117° it boils; but even at ordinary temperatures it emits reddish vapours, somewhat like those emitted by nitrous acid. It discharges the azure colour of litmus, as would happen with chlorine, and without reddening it. Like chlorine, it sets fire to certain metals when brought in contact with it. It is not combustible, and it extinguishes combustion: it acts as a strong poison, and corrodes the skin. It becomes a solid at a little below zero; but if combined with water so as to form a hydrate, it affords fine red crystals at 32°. Brought in contact with phosphorus, bromine occasions an explosion. Its vapour is not decomposed at a red heat. A taper immersed in the vapour is extinguished, after having its flame surrounded by a greenish margin topped with red. Starch is a test for bromine as well as for iodine; but it produces an orange hue, instead of the blue which iodine affords.

Bromine, like chlorine, combines either with oxygen or hydrogen, and in both cases forms an acid. The acid formed by oxygen is called *bromic acid;* that with hydrogen is *hydrobromic acid.* The former can only exist in combination with water; but the latter is a gas which water absorbs, and acquires considerable acidity and density by so doing. Chlorine also combines with bromine: the chloride is an orange volatile liquid.

The combinations of bromine are numerous, but their properties do not warrant the occupation of limited space by particular descriptions.

SECTION VIII.

Amongst the various combustible bodies with which common observation makes us acquainted, the substance called sulphur stands sufficiently characterised by its well known appearance, and the peculiar blue flame with which it burns. It is much used in the arts and manufactures. It is found in great purity in many parts of the world, especially in volcanic countries amongst lava: it occurs in masses, and sometimes in crystals; and it is an abundant ingredient in various minerals. It is of a yellow colour; is moderately hard; has a peculiar smell, which is increased by friction, or by a gentle heat. When a roll of it is held in the hand, it at length cracks in pieces. It is a non-conductor of electricity, and when rubbed becomes highly electric. When heated to 218°, it melts almost into a liquid; if heated a little more it becomes less liquid, and if much more it becomes tenacious; on cooling somewhat, it returns to its former liquidity. If it be allowed to cool until the parts next the sides and bottom of the containing vessel are solid, while the central portion is still liquid, and the vessel is slowly inclined so that the liquid part may run off, the interior will present a mass covered all over with crystals of sulphur. If, while melted and viscid, it be poured into cold water, it acquires somewhat the consistence of softened sealing-wax, and in this way it is often used for taking impressions from seals. When strongly heated, it boils and evaporates; and the vapour condenses on any cold body in the state of a fine yellow powder, called *flowers* of sulphur: the part that refuses to evaporate is called *sulphur vivum,*— an inappropriate name, and contradictory to the old name *caput mortuum,* which such residua obtained. If heated to 300° in contact with the atmosphere, it takes fire, and burns with a lambent blue flame,

which, as the heat rises, becomes whitish; even at 190° it burns, but so feebly that the quantity existing in gunpowder may be all consumed without explosion; this may be done by laying the gunpowder spread out on a moderately hot tile. Sulphur burns, in oxygen gas, with a much more brilliant and a lighter coloured flame. In either case, the sulphur combines with oxygen, and emits copious fumes, which are a compound of oxygen and sulphur; they are pungent to the smell, and acid to the taste. We are acquainted with no less than four compounds, consisting of these elements in different proportions.

Sulphurous acid.—The above mentioned fumes are the first compound: we know of no oxide of sulphur; all the combinations possess acid properties. The one at present under consideration, in conformity with the principles of nomenclature already explained, is called sulphurous acid. When quite free from water, it is a gas at ordinary temperatures and pressures of the atmosphere; but when compressed into half its bulk, it becomes a liquid; and the same happens by exposing it to an intense cold without pressure. Exposed to air, this liquid acid evaporates speedily, and produces such a degree of cold, that the mercury in a thermometer tube may be frozen by its means: it boils at 14°. The gas has a strong affinity for water; it is absorbed by $\frac{1}{33}$th of its bulk of water, and the solution thus formed is the same as what is commonly called liquid sulphurous acid; but is perfectly different from the acid liquefied by cold; for the latter may contain no water. The gas may be expelled again from its solution in water by boiling. This acid comports itself differently from other acids with regard to some vegetable colours; it instantly reddens the infusion of blue cabbage, but it discharges the colour of infusion of the red rose. The gas bleaches various textures, as those of silk, wool, and straw; the liquid acid bleaches sponge. It bears a red heat without decomposition.

When sulphur is burned in perfectly dry common

air, or oxygen gas, no product is formed but sulphurous acid; but if moisture be present, both this acid gas and sulphuric acid are produced. To generate sulphurous acid gas for experiment, mercury or copper clippings should be boiled with strong sulphuric acid, in a glass retort, and the gas received over mercury, as water would absorb it. When sulphur is burned in dry oxygen, its volume, when cold, is so little altered, that, were the sulphur quite pure, it is believed there would be no alteration whatever. In fact, it is admitted, that sulphurous acid gas contains exactly its own bulk of oxygen.

This gas has an exceedingly pungent smell; it is fatal to breathe it undiluted; it extinguishes flame; and is not inflammable. Its specific gravity, according to Davy, is 2·2293; according to Thomson, 2·221: the mean is 2·2251; and hence 100 cubic inches of it weigh 68·5596 grains. If from this last number we subtract the weight of 100 cubic inches of oxygen, 33·9153 grains, the remainder, 34·6443 grains, are the weight of 100 cubic inches of sulphur vapour, such as exists in sulphurous acid. Hence, I conceive the specific gravity of vapour of sulphur must be 1·1244, and not 1·1111, as stated in chemical works. If we suppose a volume of sulphur vapour and a volume of oxygen to condense into a volume of sulphurous acid, the supposition will just accord with the known specific gravity of the latter; for $1·1244 + 1·1007 = 2·2251$.

Sulphuric acid. — It has been already mentioned that dry oxygen gas does not act upon dry sulphurous acid gas; but if water be present, a combination is effected, and sulphuric acid is formed. The most instructive mode of making the experiment is the following: — Pour some liquid sulphurous acid into a flat vessel, and invert a jar of oxygen gas over the acid, so that its surface may be in extensive contact with the oxygen. After some time the quantity of oxygen will begin to diminish, and the liquid will slowly rise in the jar, until at length all the oxygen (if its quantity was exactly apportioned) will disappear. The sulphurous

acid is now totally altered: it has lost its suffocating smell; it may be boiled without expelling any gas, and instead of discharging the colour of the red rose, it renders it more intensely red: it is now converted into sulphuric acid, although very much diluted with water. If the liquid be boiled until its specific gravity become 1·845, it is then the strongest sulphuric acid that can be obtained.

The process just described is very different from that made use of on the large scale for obtaining commercial sulphuric acid. Formerly it was procured by the distillation of common green or white copperas, that is, sulphate of iron or of zinc. When sulphate of iron is exposed to heat in a retort, it first gives off water of crystallisation; this was called *phlegm* of vitriol; it is a little acidulous: next comes a tolerably strong acid, which was called *spirit* of vitriol; and, lastly, the strongest portion, which, from its consistence, was called *oil* of vitriol: the latter part of this becomes solid, owing to its great concentration, and was called *glacial* oil of vitriol; it possesses the property of smoking. From 6 cwt. of common sulphate of iron, Bernhard obtained, by distillation, 52 pounds of dry concrete acid — (*Hopson's Wiegleb*).

In 1703, Homberg published a paper in the Memoirs of the Royal Academy, in which he described a method of obtaining spirit of sulphur by burning sulphur in a wide receiver. But this must have been done to great disadvantage; for Geoffroy informs us, that by the process, 1 pound of sulphur sometimes yields 1½ ounce of the acid spirit, and this he considers a great product. That it was then a great product, and the process a real improvement, appears from "The Booke of Distillations," which gives the following method: —Throw brimstone in small quantities into a pan of earth or iron placed on the fire. Keep a bell glass hanging over it, but not so near as to confine the vapours, and thus extinguish the flame. As the brimstone burns, supply more; "a dark red oyle will collect, and this conceive that of five pounds

of brimstone you shall hardly gather one ounce of oyle." Such was the produce two centuries and a half since. Homberg, however, was not the inventor of the improved process, for it is mentioned in Margraaf's Materia Medica Contracta, published twenty years before.

In some time after, Cornelius Drebbel, a Hollander, discovered a method of obtaining 10 ounces of the acid spirit from a pound of sulphur; but the process was kept secret.

The next great improvement in the manufacture was, the discovery that, by adding nitre to the sulphur during the burning, the access of external air, which used to carry off the acid fumes, was rendered unnecessary, and that a much larger product might thus be obtained. This had a considerable effect in reducing the price of the acid; from 2*s.* 6*d.* per pound, it fell to 1*s.*, and then to 10*d.*; a short time previously to 1758 it was reduced to 4*d.* — (*Elaboratory laid open*, 158.); and at present it is sold in London for scarcely more than a quarter that sum. A patent had been granted to some persons, a few years before 1758, for this invention; but on the grounds of novelty they had no title to such, for the nitre process is actually described by Lemery, in his *Cours de Chimie*, 1713.

Until 1807, when the theory of Clement and Desormes was first promulgated, the practice throughout Great Britain had been to enclose a number of plates of iron, containing a mixture of one part of nitre to nine of sulphur, in a state of combustion, in a chamber of lead, which was made as close as possible by means of water lute. This was done accordantly with the improvement above mentioned, of preventing the acid fumes from being carried off; but it will presently appear that the closeness of the chamber was of the greatest possible detriment to the process, because it excluded common air, and because a crust of hard salt, which could not be broken, formed on the surface of the burning melted matter, and prevented perfect combustion. Up to this period, it was considered good produce to obtain five

parts by weight of sulphuric acid from four of sulphur*; and often the average produce did not exceed equal weights. But as soon as the theory of Clement and Desormes became known, the necessity of admitting the atmosphere was perceived; rakes were applied to the burning matter; and such was the effect on the produce, that from 1 pound of sulphur no less than 2½ or 3 pounds were obtained, and from 6*d*., to which the price had risen, it was reduced to 2*d*. per pound.

Instead of burning the mixture of sulphur and nitre in the chamber, a stratum of water being laid on its floor to absorb the acid fumes, the present practice is to burn the mixture on an iron pan, in a furnace outside the chamber, so contrived that the fumes shall enter the chamber, and be there condensed in the water: no air passes into the chamber but what goes over the burning sulphur. According to the old process, the crust of salt from the pans often fell into the acid, and rendered it foul; this is prevented by the new plan. If the combustion of the nitre and sulphur be allowed to proceed too rapidly in the furnace, there will be little or no sulphuric acid formed in the chamber; the sulphurous acid and nitrous gas will be perceived in the most remote chamber, without condensation; and, perhaps, unacidified sulphur will be sublimed. Suppose that a charge of 1 cwt. of the mixture of sulphur and nitre is burned at once, three such charges will be consumed every twenty-four hours; a new one being added when the former is nearly burned out: each charge is to be continually raked, especially near the end of its combustion. The water in the bottom of the chamber absorbs the fumes, and increases in specific gravity, at first more rapidly than afterwards: when it arrives at 1·350, if it gain 3° of Twaddle's hydrometer (*i. e.* specific gravity 0·015) every day until it attain 1·450, it is accounted good work, the depth of the water being 5 or 6 inches, and the height of the chamber 12 feet. In some vitriol works, when the acid reaches 1·450, the

* Irvine's Essays, p. 413.

impregnation is discontinued; it is then concentrated by evaporation in leaden boilers, until it become 1·600. At a strength very little beyond this, the acid would act upon lead; and so high is the boiling point become, that the lead would be in danger of melting. On these accounts, it must be transferred to glass or platinum retorts or matrasses, in which it is boiled down or distilled, until it be of specific gravity 1·845, or 1·850. The liquor which boils off in vapour is at first water; then liquid sulphurous acid; and, lastly, sulphuric acid. The test of completion is, that the acid, originally deep brown, has become perfectly colourless. The cause of the brown colour is excess of sulphur; this decomposes the sulphuric acid, and hence sulphurous acid appears: there is thus a waste, although but trifling. Sulphur boiled on sulphuric acid, turns it blue, green, or brown, according to the quantity of sulphur. It is proper to observe that, in some factories, the impregnation of the water by the gas in the leaden chambers is continued until the specific gravity be 1·600; it is then transferred at once to the platinum retorts.

The leaden chambers at length, but slowly, are corroded and wear out; the sides and top most, the bottom least; but most of all near the source of heat. I have known lead of six pounds to the square foot, to stand moderate work for fourteen years. About half a pound of the combination of lead with sulphuric acid is found, after the perfect concentration of a retort charge which afforded 150 pounds of acid; and a little more remains dissolved in the acid, which dilution precipitates.

The residuum remaining after the burning of the sulphur and nitre is sold to alum makers, soda makers, and soap boilers.

The following is the theory of Clement and Desormes, as improved by sir H. Davy: — "The sulphur, by burning, forms sulphurous acid gas, and the acid in the nitre is decomposed, giving off nitrous gas; this, coming in contact with the oxygen of the atmosphere, produces nitrous acid gas, which has no action upon sulphurous

acid, to convert it to sulphuric acid, unless water be present; and if this substance be only in a certain proportion, the water, the nitrous acid gas, and the sulphurous acid gas combine, and form a white crystalline solid. By the large quantity of water usually employed, this compound is instantly decomposed, oil of vitriol formed, and nitrous gas given off, which in the air again becomes nitrous acid gas; and the process continues, according to the same principle of combination and decomposition, till the water at the bottom of the chamber is become strongly acid. It is easy to prove the truth of these reasonings. Let dry sulphurous acid gas and nitrous acid gas be mixed together, by suffering the sulphurous gas to pass into a glass globe partially exhausted, and containing nitrous acid gas, there will be no action between the gases; but if a drop of water be introduced, there will be an immediate condensation, and a beautiful white crystalline solid will line the interior of the vessel: whereas, if the globe contain plenty of water, nitrous gas will be given off with great violence, and the water will be found to be solution of oil of vitriol." It is evident that the azote, which is continually accumulating in the leaden chamber, must constantly be allowed to escape.

The following are the chief properties of sulphuric acid: — When mixed with water, heat is generated. If the acid weigh four times as much as the water, and both are at 50°, the temperature will rise to 300°, and there will be a diminution of volume. Such is the attraction of this acid for water, that it will, when exposed to the atmosphere, attract moisture from it, and will thus gradually become much diluted. The greatest degree of concentration to which pure sulphuric acid can be brought by boiling, is specific gravity 1·845*; and even at this strength, every 100 parts weight contain 18·37 parts of water. The acid of commerce, as it comes from the manufacturer, is 1·850; but it is so in consequence of its containing salts of lead, or of earths, or of potash.

* Perceval, Irish Trans. iv. 89.; and Ure's Dictionary.

It may be purified from these by distillation over a charcoal fire in a green glass retort, on the bottom of which some bits of glass or platinum should lie, to prevent continual concussions arising from the vaporisation of the acid under so heavy a liquid, which might endanger the vessel. The portions that first distil contain the water present, along with any sulphurous acid that may have been generated by the accidental mixture of carbonaceous matter; these should be rejected. The second portions that come over will be very pure; but the phial in which it is kept must be well closed, to prevent dilution by atmospheric moisture. Sulphuric acid, colourless when pure, becomes discoloured by any carbonaceous matter falling into it; a bit of cork would effectually blacken it. Boiling is the remedy; for the carbon is expelled as carbonic acid, along with the sulphurous acid generated by the abstraction of oxygen by the carbon.

Sulphuric acid freezes when sufficiently cooled, and the crystals are sometimes large, distinct, and hard: when of specific gravity 1·780, Mr. Keir found it to crystallise on being cooled in melting snow (32°); and if stronger or weaker, it required a greater cold: but the temperature of the crystals, when formed, was so high as 45°.* This does not correspond with the extensive experience of a scientific vitriol manufacturer, who informed me that the specific gravity of the acid which he found to freeze most easily, is 1·835.

Saxon or Nordhausen sulphuric acid is made in the following manner:—Green copperas (sulphate of iron) is calcined to a yellowish red; it is thus freed from the chief part of its water, and is reduced to half its weight. While still warm, it is distilled from large earthen retorts in a reverberatory furnace: it gives some acidulous water; the acid then comes over. Its specific gravity is sometimes as high as 2·0. The distillation of a batch of retorts often continues ten days. If the calcined copperas were not immediately distilled, it would attract moisture. Such is the process described by Gren and Wiegleb.

* Philosophical Transactions, by Hutton, &c. xvi. 271.

This acid, when exposed to air, discharges whitish gray vapours, which are not sulphurous acid, as formerly supposed, but real dry sulphuric acid. Acid of specific gravity 1·896 contains about $\frac{1}{10}$th of water; and is so volatile, that it boils at 120°.—(*Thomson.*) If it be distilled into a receiver cooled with snow, the fuming portion comes over first, and concretes into a fibrous solid like *asbestos*, which is far more volatile than ever, and is pure sulphuric acid; all the water remains in the portion contained in the retort, which is now common sulphuric acid.

From these facts it therefore appears, that perfectly pure and *anhydrous* * sulphuric acid is a white solid substance, so extremely volatile, that it discharges vapours of sulphuric acid into the air; these attract moisture, and both condense into visible particles: and that, if to 81·63 parts of it, 18·37 parts of water be added, both by weight, the result is ordinary sulphuric acid, which, instead of being volatile like the original, requires a heat above 600° to make it boil. Further additions of water render it more volatile; but it is obvious that the boiling point can never fall lower than 212°, be the acid ever so dilute, although the pure acid boils below 120°. The solid acid, Dr. Ure says, if dropped on paper, will burn holes in it with the rapidity of a red-hot iron; dropped into water, it hisses as if a red-hot coal were thrown in: at 64° it melts into a thin liquid. The analysis of sulphuric acid is readily performed in the manner pointed out by Davy. Let the strongest acid of commerce be passed in vapour through a red-hot porcelain tube; part of it will be decomposed into two volumes of sulphurous acid and one of oxygen. The water, with which the decomposed acid had been in combination, will mix with the portion of acid which escaped decomposition. Sulphuric acid is, therefore, composed of two volumes of sulphurous acid and one of oxygen, condensed into a liquid. 200 cubic inches of sulphurous acid weigh

* That is, without water.

137·1192 grains, an equal volume of which is oxygen, and weighs 67·8306. The 200 volumes of sulphurous acid, in becoming sulphuric, take up 100 cubic inches of oxygen, weighing 33·9153 grains; which, added to the oxygen already in the sulphurous acid, gives as the total oxygen, 101·7459 grains: but, in the 200 cubic inches of sulphurous acid, there are 200 cubic inches of sulphur vapour, weighing 69·2886 grains. Hence, sulphuric acid consists of 101·7459 grains of oxygen and 69·2886 grains of sulphur; and, consequently, 100 grains of sulphur combine with 146·843 grains of oxygen, to form anhydrous sulphuric acid: or 200 volumes of sulphur vapour combine with 300 volumes of oxygen, the volume of the latter being 1½ time as much as exists in sulphurous acid.

Hyposulphurous and *Hyposulphuric acids.* — Beside sulphurous and sulphuric acids, there two other combinations of sulphur with oxygen which contain a less proportion of oxygen than these acids respectively, and they are both acids; hence, one is called *hyposulphurous* acid, and the other *hyposulphuric* acid. To produce the former, 100 parts, by weight, of sulphur combine with 24·474 of oxygen. To form the latter, 100 of sulphur combine with 122·369 of oxygen. Hyposulphurous acid has been obtained in an uncombined form; at least, in combination only with water; but, even in a few hours, it undergoes spontaneous decomposition. Hyposulphuric acid has been procured in solution in water, the specific gravity of which may be raised, by evaporation, to 1·347; but, if the heat be continued beyond this density, the liquid is resolved into 4 parts by weight of sulphurous acid gas, which exhales, and 5 of sulphuric acid, which is the only remaining product. Hence these relative quantities of tho two acids, combined, constitute hyposulphuric acid.

Subsulphurous acid. — There is one more compound of sulphur with oxygen: it contains a quantity of oxygen, intermediate between sulphurous and hyposulphurous acid; and is called by Dr. Thomson, who first

pointed out its exact nature, *subsulphurous* acid, as containing a lower ratio of oxygen than what is contained in sulphurous acid, and yet distinguished from that in which the ratio is still lower, viz. hyposulphurous acid. In subsulphurous acid, 100 parts of sulphur are combined with 48·948 parts of oxygen. The following table shows the composition of the compounds of sulphur and oxygen by volume and weight: —

	Volumes. Sulp vap.		Ox.		Grains weight Sulph.		Oxygen.		Ratio of ox.
Hyposulphurous acid -	100	+	25	or	100	+	24·474	or	1
Subsulphurous acid -	100	+	50	or	100	+	48·948	or	2
Sulphurous acid -	100	+	100	or	100	+	97·896	or	4
Hyposulphuric acid -	100	+	125	or	100	+	122·369	or	5
Sulphuric acid - -	100	+	150	or	100	+	146·843	or	6

The ratio of oxygen in these compounds is as the numbers 1, 2, 4, 5, 6. Were a compound hereafter discovered in which the volume of oxygen would be 75, we should then have the series of natural numbers complete. In all probability such a compound exists.

Sulphuretted hydrogen, or *Hydrosulphuric acid.* — Sulphur has an affinity for hydrogen, and unites with it in two proportions. If sulphur be heated in a flask of hydrogen, the latter dissolves some sulphur, and a gas is produced by the union, which has an intolerably fetid smell, resembling that of eggs in the last stage of putrefaction; indeed, the smell of putrid eggs is owing to the emission of this gas. But by this process the hydrogen does not take the quantity of sulphur which would be necessary to form even the first combination; about half of the hydrogen remains altogether unchanged. In order to procure the perfect combination, hydrogen must be generated in contact with sulphur; and, while in the nascent state, it will saturate itself in the first degree. The substance sold by druggists, under the name *crude antimony*, or sulphuret of antimony, is a combination of sulphur and the metal antimony; if strong muriatic acid be heated on this substance, in weight about six or seven times that of the antimony, an effervescence will take place; hydrogen will be

formed; and it will instantly saturate itself with sulphur, so far as to form the gas in question. This compound is sulphuretted hydrogen. It is collected over water, in vessels filled with water in the usual manner. But as little water as possible should be used, as it absorbs 3·66 times its bulk of the gas, and occasions so much waste. The gas is, at the same time, purified from any muriatic acid fumes which might have passed off along with it. Water, thus impregnated, is found abundantly in nature ready formed; it constitutes the sulphurous springs of Harrogate, Aix-la-Chapelle, Kilburn, &c. The sulphuretted hydrogen may be expelled, unaltered, by boiling the water.

If a stream of sulphuretted hydrogen be passed through water tinged with a vegetable blue, the colour is changed to red, in the same way as it would be were carbonic acid passed through it, or any other acid. This gas combines with other bodies, and comports itself like an acid, except that its taste is not sour. Some years since, when chemists imagined that oxygen was the acidifying principle, and that nothing could be an acid that did not contain it, the properties of sulphuretted hydrogen were considered anomalous and irreconcilable. Now it is ascertained that, to constitute acidity, oxygen is by no means necessary, and hydrogen is known to produce acids in conjunction with other bodies.

Sulphuretted hydrogen has been named by the Germans *hydrothionic* acid (θειον, sulphur); the French call it *hydrosulphuric* acid. If 100 cubic inches of it be mixed with 150 cubic inches of oxygen, both dry, and an electric spark passed through, an explosion takes place, water is formed, and the 250 condense into 100 cubic inches of sulphurous acid. Now, hydrogen, in combining with sulphur, does not alter its volume; it is, therefore, evident, that 100 cubic inches of sulphuretted hydrogen contain just the same volume of hydrogen. To form water, the 100 cubic inches of hydrogen must have removed, and combined with 50 cubic inches of oxygen; leaving 100 cubic inches of

oxygen to form sulphurous acid with the whole sulphur present. As oxygen, in combining with sulphur to form sulphurous acid, does not alter its volume; and as half the weight of 100 cubic inches of sulphurous acid gas is sulphur, amounting to 34·6443 grains; it is manifest that this was the weight of sulphur contained in the original 100 cubic inches of sulphuretted hydrogen; and if the weight of 100 cubic inches of hydrogen, viz. 2·1197 grains, which is the whole quantity originally present, be added, we then have 36·764 grains, as the weight of 100 cubic inches of sulphuretted hydrogen. From this, by the rule of three, we calculate, that, as 30·8115 grains of common air (the weight of 100 cubic inches of it) are to 36·764 grains (the weight of the same measure of sulphuretted hydrogen), so will the number 1·000, or unity, be to the number expressing the specific gravity of sulphuretted hydrogen, or 1·1931. This is the calculated specific gravity; experiment has given the number almost exactly the same: Gay-Lussac and Thenard found it 1·1912.—(*Thenard, Traité Elémentaire*, i. 234.)

This gas neither supports combustion nor life; it is one of the most poisonous gases known; experiments have been made which prove that so small an admixture as $\frac{1}{250}$th of it with common air is capable of killing a horse, if breathed; a greenfinch instantly died in air containing $\frac{1}{1500}$th of its volume: and it has been shown, that enveloping the body of a young rabbit in sulphuretted hydrogen, the head being in the open air, killed it in a quarter of an hour. It extinguishes flame instantly, but easily catches fire from a candle, and burns with a bluish flame, provided that the jet of gas is in contact with air. A few drops of strong nitric acid let fall into a vessel filled with sulphuretted hydrogen, sets fire to it. I suffered a severe injury from an accident of this kind, twelve years since, long before Berzelius announced the accension of sulphuretted hydrogen by nitric acid. I had poured muriatic acid on sulphuret of antimony in a very large

matrass; and while the vessel was partly filled with sulphuretted hydrogen, and partly with common air, I poured in a little nitric acid, when instantly the matrass was shattered, and my hands were severely injured. In such experiments the two acids should be previously mixed, before they are poured on the sulphuret.

Sulphuretted hydrogen may be easily recognised, even when largely mixed with other gases, by its power of blackening silver, and the dry powder called *white lead.* The wood-work of rooms, painted with white lead, is often darkened by human exhalations containing this gas; and articles of plate are blackened by the same cause.

This gas may be condensed by pressure into a liquid; but it recovers the gaseous state, with energy, when the pressure is removed.

Bisulphuretted hydrogen, or *Hydroguretted sulphur.* — This compound contains twice as much sulphur as the preceding; the following is an easy process, given by Dalton, for obtaining it:—Let half an ounce of flowers of sulphur, and as much slaked lime, be gently boiled together in a quart of rain water for one hour; more water may be added as it evaporates. After cooling, a clear yellow liquid is obtained. To six ounces of this liquid put half an ounce of muriatic acid, and stir them. In a short time the mixture exhibits a milky appearance, and this becomes interspersed with brown oily dots, which gradually subside into an adhesive matter of a semiliquid form at the bottom. The liquid may then be poured off, and the brown matter washed with water, which is to be poured off. From 20 to 40 grains of this brown oily substance will be obtained. "If a portion of it touch the skin, it requires a knife to scrape it off. When a little of it is applied to the tongue, a sensation of great heat, and a bitter taste, are felt; the saliva becomes white like milk." When heated, sulphuretted hydrogen exhales, and sulphur remains. Very little is known of the nature of this compound; it is a

feeble acid, and combines with alkaline substances. From Thomson's experiments it may be inferred, that, to form bisulphuretted hydrogen, 100 parts, by weight, of sulphur, combine with 3·0592 of hydrogen. That quantity of hydrogen would require but 50 parts of sulphur to form sulphuretted hydrogen.

Bisulphuret of carbon. — Sulphur combines with carbon, and forms a liquid which formerly had the absurd name of *alcohol of sulphur,* but is now called *bisulphuret of carbon.* It may be formed by distilling the mineral called *iron pyrites,* mixed with one fifth of its weight of newly burnt charcoal, both in fine powder, from a stoneware retort, coated with Stourbridge clay, and placed in a furnace. The beak of the retort is to have a long glass tube luted to it, one end of which plunges into a vessel of water. By a strong heat a yellow liquid distils over, and falls to the bottom of the water, from which being separated, it is re-distilled in a glass retort with a very gentle heat. This liquid is sulphuret of carbon.

When thus rectified, it is transparent and colourless; its boiling point is about 108°; its specific gravity is about 1·266: when exposed to air, it evaporates rapidly, and produces intense cold, such is its volatility. If a thermometer tube, with a bit of muslin tied round the bulb, be dipped in this liquid, then included in an air-pump receiver, and the air exhausted, the evaporation produces such cold that the mercury freezes. And if a few drops be diffused on the surface of a glass of cold water, the bisulphuret will begin to evaporate so rapidly, and such cold will be produced, that whatever remains will become cased in a shell of ice. It takes fire at a temperature very little above that of boiling mercury, burns away, and is resolved into carbonic and sulphurous acids. Its vapour, if mixed with oxygen, explodes by the electric spark with considerable noise: and if mixed with deutoxide of azote, and transmitted through a jet-pipe, it burns with a somewhat greenish beautiful light. It dissolves camphor,

and is converted into a substance resembling camphor, by the action of a mixture of nitric and muriatic acids. It dissolves in alcohol and ether, but not in water. It appears to combine with alkalies and earths. Its smell is strong and fetid. 100 parts by weight consist of 84·83 sulphur and 15·17 carbon.

Xanthogen and *Hydroxanthic acid.* — Although bisulphuret of carbon does not appear to be an acid, a combination of carbon and sulphur is capable of acting as an acidifiable base, and forming an acid when combined with hydrogen. In this case, the combination of sulphur and carbon constitutes a compound radical, no doubt different in the ratio of its elements from the bisulphuret; and, when acidified by hydrogen, is to sulphuret of carbon what hydrocyanic acid is to cyanogen. On account of the yellow compounds which this combustible radical is capable of producing with certain metals, it has been called *xanthogen* (from ξανθος, yellow), and to the acid which it forms by combination with hydrogen, the name hydroxanthic acid has been given. It has also been called *hydrocarbosulphuric* acid.

Dr. Zeise, professor of chemistry at Copenhagen, the discoverer of this acid, states, that although bisulphuret of carbon does not redden litmus, it neutralises an alcoholic solution of a pure alkali: for the alkali determines the formation of hydroxanthic acid by the re-action of itself and the alcohol. If a concentrated alcoholic solution of potash, neutralised with bisulphuret of carbon, be mixed with diluted sulphuric acid, and in a few moments after with a large quantity of water, a transparent, oil-like, yellow, strong-smelling liquid, is separated, which should be immediately well washed with water. This is hydroxanthic acid. Its taste is acid, and then astringent and bitter. It reddens litmus paper, and then changes it to yellowish white. It is insoluble in water, and is specifically heavier than that fluid. It is easily inflamed, and while burning dif-

fuses the smell of sulphurous acid. It is decomposed by heat.—(*Annales de Chim. et de Phys.* xxi. 160.)

There are two other acids known, which are composed of the same elements as hydroxanthic acid, although very dissimilar in their properties: they are called *vegeto-sulphuric* acid, and sulpho-naphthalic acid. It will save space to refer vegeto-sulphuric acid to future consideration.

Sulphonaphthalic acid is obtained by causing strong sulphuric acid to act on naphthaline. A red crystalline compound results: this is dissolved in water; the solution is saturated with baryta: sulphate of baryta precipitates, and, being separated, the solution of sulphonaphthalate of baryta is decomposed by sulphuric acid, and filtered. This liquid is the acid required. When the water is removed, it becomes a white, deliquescent, easily fusible solid, of an acerb acid taste. It is composed of carbon, hydrogen, and sulphuric acid: the saturating power of the sulphuric acid is reduced to half by combination with the carbon and hydrogen.

Sulphurets of cyanogen and *Sulphocyanic acid.*—Sulphur combines with cyanogen in two proportions, and forms two distinct compounds. To form the first, 100 parts of cyanogen combine with 31 of sulphur; but in the second compound there is four times that quantity of sulphur. The latter sulphuret of cyanogen is known to act the part of an acidifiable base, and by combining with hydrogen to form an acid, which is called *hydrosulphocyanic acid*, or, simply, *sulphocyanic*. This acid is capable of crystallising at a very low temperature: its smell resembles that of acetic acid: its taste is sour. But its chief distinguishing property is its producing a deep blood-red colour when dropped into any solution which contains peroxide of iron: the two substances act as tests of each other's presence. This acid combines with sulphuretted hydrogen, and forms *hydrosulphuretted sulphocyanic acid.*

Chloride of sulphur.—If a glass flask be filled with

dry chlorine, and a bit of sulphur introduced, they will combine if heated, and form a reddish coloured liquor, which smokes in the air. Its specific gravity is 1·700: it boils below 200°. It does not manifest acid properties. It decomposes water, the oxygen of which combines with some of the sulphur, forming sulphurous and sulphuric acids; the hydrogen combines with the chlorine, forming muriatic acid, and some sulphur is precipitated.

SECTION IX.

SELENIUM.

The substance now to be considered is nearly allied to sulphur in its nature, although it in some respects partakes also of the nature of a metal. There is a copper-mine in Sweden, near Fahlun, celebrated for its antiquity, and its enormous produce. Besides copper, the mine affords vast quantities of iron combined with sulphur, and to such extent, that it has been found worth while to extract the sulphur, although it is exceedingly impure. The sulphur is consumed in the manufacture of sulphuric acid. After the combustion and acidification of the sulphur, and the absorption of the acid fumes by the water used in the process, a reddish brown substance is found to subside, consisting of a great proportion of sulphur mixed with other ingredients. If some of this reddish brown substance be strongly heated, it emits a pungent smell resembling that of horseradish.

By complicated processes, it is possible to separate the odorous substance from the reddish brown matter. This substance seems to partake of its sulphurous origin; for it in many respects resembles sulphur in its properties: and, on the other hand, it possesses so much of the metallic character, that its discoverer, Ber-

zelius, did actually pronounce it a metal. At first he mistook it for the metal called tellurium; but afterwards he ascertained that they are different substances, yet resembling each other in some of their qualities. Tellurium having been so named from *tellus*, the Latin name of our planet, Berzelius named the new metal, as he considered it, *selenium*, from σελήνη, the moon,—thereby suggesting the relation of the two metals by the relation of the two planets.

Since the discovery of this substance, it has been found in the pyrites of the isle of Anglesey, and may be detected in the sulphuric acid manufactured from the sulphur extracted from that mineral. It has been also found in the sulphur of other countries.

Selenium, under certain circumstances, has considerable metallic lustre; but it has not the opacity of a metal; for, when reduced to thin plates, it is semitransparent. Unlike a metal, it is a non-conductor of electricity; and, unlike sulphur, it is a non-electric. Its colour varies according to circumstances: if examined by transmitted light, or, in plain terms, if *looked through* as a transparent body, it appears reddish; but if seen by reflected light, that is, *looked at* in the ordinary manner of opaque bodies, it is leaden gray and brilliant. It breaks with a vitreous fracture, somewhat like sulphur; and it may be reduced to a powder, which is red coloured. Like sulphur, also, when subjected to heat in a large glass globe, it sublimes into flowers, but of a reddish brown colour; while in vapour its colour is yellow, somewhat like the vapour of sulphur. At the temperature of 212°, it softens; and if heated a little more, it melts: at a little above 600° it boils, and distils over into drops of a metallic appearance. When it has been fully melted, it will preserve, while cooling, a certain degree of ductility, and may be drawn out into threads like sealing-wax; and these have a metallic lustre, although somewhat transparent. It is insoluble in water. Its specific gravity is 4·300. In the flame of the blowpipe it disappears, communicating an azure

colour to the flame, and a highly diffusible smell of horseradish: such are its characteristic qualities.

Oxide of selenium.—Selenium combines with oxygen, and forms an oxide and two acids, the properties of which have not been fully ascertained. The oxide exists in the form of a gas. It may be produced by heating selenium in a flask of common air.

Selenious acid may be formed by passing oxygen over selenium heated to about 600° in a small vessel, from which it cannot readily escape in vapour; the selenium takes fire, combines with oxygen, and forms the acid in question. It sublimes into crystals, the form of which somewhat resembles those of nitre. While in vapour, its colour is yellowish green, resembling chlorine. It is very soluble in water and strong alcohol; the taste of its solution is acid, and a little acrimonious; its aqueous solution, when concentrated, crystallises. The same acid may be formed by the action of nitre or nitromuriatic acid on selenium: a solution is effected; and this, when evaporated to dryness, affords a white mass of selenious acid, which may be crystallised either by sublimation or in the usual manner.

Selenic acid.—By means of a new addition of oxygen to selenious acid we obtain *selenic acid:* and here, again, is observable the resemblance of selenium and sulphur; for selenic acid possesses many of the properties of the sulphuric. Selenic acid is decomposed, at so low a temperature as 536°, into selenious acid and oxygen. When mixed with water, it causes a considerable elevation of temperature, just as sulphuric acid would. If to its aqueous solution some muriatic acid be added, and a plate of zinc or iron be immersed, selenium is reduced in the form of a powder, the colour of which varies. This precipitation, by means of a metal, corresponds with the pseudo-metallic nature of selenium. To form selenious acid, 100 parts of selenium combine with 40 of oxygen; and with 60 to form selenic acid.

Seleniuretted hydrogen.—Another point of resemblance subsisting between selenium and sulphur is, that both

bodies combine with hydrogen, and form a fetid gas, which possesses the properties of an acid. By acting on a combination of selenium with iron or potassium, by means of muriatic acid somewhat diluted, a combination of hydrogen with selenium will be evolved in the form of a transparent and colourless gas. One of its most striking properties is the effect which it produces when even the smallest quantity is snuffed up the nostrils: there is a painful irritation produced, which gradually diffuses itself down the throat, accompanied by a temporary loss of the sense of smelling, a violent cough, and considerable expectoration; all of which unpleasant effects continue for many days. It is the opinion of professor Berzelius, that to inhale much of this gas might be a dangerous experiment.

This gas, in conformity to the names given to other combinations of hydrogen with inflammables, is called *seleniuretted hydrogen.* Its smell resembles that of sulphuretted hydrogen. It consists of 100 parts of selenium combined with 2·5 of hydrogen. It is copiously absorbed by water; and the liquid produced, like sulphuretted hydrogen, possesses the properties of an acid, and precipitates metallic salts; it stains the skin of a brown colour. Selenium combines with sulphur, chlorine, and carbon.

SECTION X.

PHOSPHORUS.

This well known substance, though sold at the low rate of 3*s.* per ounce, is prepared by an exceedingly difficult process. Several methods of preparation have been given, all of which have their disadvantages. Macquer gives, from Hellot, a process which occupies seven pages. To make an ounce of phosphorus, the first step is to evaporate three hogsheads of fetid urine to dryness. This specimen is enough; it is not necessary to describe the process further. It is no wonder

that Scheele's method of making it from bone ashes was universally employed as soon as discovered. But even this mode is wasteful and excessively troublesome. Bone ashes, decomposed by sulphuric acid in the manner hereafter described, are but partially acted on: much of the bone remains unaltered, unless a large ratio of sulphuric acid be employed; and this excess gives rise, in the common process, to much trouble, loss, and diminution of the product.

In order to obtain phosphorus, prepare pyrophosphoric acid* from bone ashes, in the manner hereafter described. It must be perfectly dry, and immediately reduced to powder in a hot mortar, and mixed with half its weight of newly made charcoal in fine powder. An earthenware retort must be in readiness, rightly prepared: its pores must have been closed by washing with a mixture of two parts of finely powdered borax, one of powdered lime, and a little water; so that a coat of glass will be formed on it during the incandescence of the vessel. It must then be evenly coated over with a mixture of Stourbridge clay and pounded crucibles, mixed with cut tow and a little water, and allowed to dry slowly. The retort, charged with the above mixture, is placed in an air-furnace, with an opening before to admit the neck, which should have a wide copper tube, 20 inches long, luted to it; the other end, to prevent access of air, being immersed in a basin of water so as to be barely covered. The belly of the retort is supported on a brick lying on the bottom of the furnace. The fuel, compactly disposed all round the retort, must now be kindled; and the heat, kept very moderate for two hours, must be increased until it become fierce. Much gas bubbles from the surface of the water, which burns brilliantly when the bubbles burst in the air: lambent luminous fumes undulate through the air over the water in a singular and beautiful manner; and at length vapour of phosphorus condenses in the copper tube, which must

* This is the substance that was formerly called *glacial phosphoric acid.*

occasionally be drawn down with a wire, and left in the water. This is impure phosphorus: it will be a successful process, if the phosphorus weigh one quarter the quantity of vitreous pyrophosphoric acid employed.*

Another method is, to decompose bones by sulphuric acid, as hereafter described; and when the acid is washed out, it is mixed with solution of sugar of lead. The sediment, or precipitate, that appears, is separated, perfectly dried, mixed with one sixth of its weight of lamp-black, and distilled as before directed.

I have gone through the process for obtaining phosphorus very many times; and may venture to state, that unless all the conditions above described are complied with, there will either be no product, or a deficient one.

Phosphorus, when pure, is transparent and colourless: I have sometimes obtained it nearly as much so as an irregular mass of glass: bleached bees' wax will give a good idea of newly distilled phosphorus, as to the degree of solidity, and the manner in which it cuts with a knife. It melts at 108°, according to Dr. Thomson; but this must take place under water, for it would burn at that temperature in the air. It is slightly soluble in both fixed and volatile oils, in alcohol and ether. It boils at 554°, but, in a vacuum, evaporates gradually at 219°. Its specific gravity is 1·748. It is capable of crystallising into octahedrons, or, as others say, into dodecahedrons. Friction or percussion sets fire to it. Letters or lines traced with it appear luminous in the dark: but there is danger in the tracing, as the phosphorus often takes fire, and by melting falls on the person's clothes, and it is almost impossible to extinguish it: the best way is to smother the flame with a very wet cloth held firmly pressed on the part. It may be distilled in a retort, if the air be exhausted: this method answers for purifying it from charcoal, which generally fouls it when first distilled: but an easier method is to tie it up in a piece of glove, or alum-leather, to immerse it in cold water, and gradually heat the water until the phosphorus melts: by pressing the leathern

* Dr. Higgins, Minutes of a Philosophical Society, p. 254.

bag under water, the phosphorus will strain through the pores quite pure, in the same way as mercury would. It should be preserved under water; as, even at ordinary temperatures, it undergoes a slow combustion in the air. Phosphorus burns in common air with a brilliant white light, but in oxygen gas the combustion is transcendently brilliant: white fumes are formed in abundance, which condense into a solid acid. When introduced into chlorine at ordinary temperatures, it takes fire also, and burns with splendour: a smoke arises, which condenses into a dry chloride. According to Dr. Bache, of Philadelphia, it is inflamed by powdering it with animal charcoal at 60°. Its combinations are very numerous.

The compounds of phosphorus with oxygen have been investigated by several chemists of eminence, but the knowledge of them acquired is not commensurate with the labour that has been bestowed on them. It is, as yet, mere matter of supposition, that phosphorus combines with oxygen so as to form an oxide. But it readily forms compounds which have decidedly acid properties. Three such are known: they are called, 1. Phosphoric, of which there are two varieties, phosphoric and pyrophosphoric acid; 2. Phosphorous; and, 3. Hypophosphorous acids.

Phosphoric and *Pyrophosphoric acids.*—When phosphorus is exposed to common air, at its ordinary temperature and degree of moisture, it undergoes a slow combustion, and absorbs oxygen: it is luminous in the dark, and emits luminous smoke, which has a strong odour of garlic: the surface becomes moist, for the moisture of the air is absorbed as well as the oxygen: the moisture trickles down; more is formed; and at length the whole is transformed into a dense liquid, of an exceedingly acid taste. This has been by some considered a distinct acid, and it obtained the name of *phosphatic* or *hypophosphoric* acid. It is at present, however, believed to consist of a mixture of phosphoric and phosphorous acids. The higher the temperature at which this process is conducted, the more speedily the changes

take place; and the quantity of acid will be greater, if a bell glass be kept over the phosphorus, the contained air being often renewed. In order to convert this dense acid liquor into pure phosphoric acid, expose it in a state of considerable dilution for a long time to the air, in order to absorb oxygen; or, add nitric acid to it in proportion of one twelfth the weight of the original phosphorus; evaporate by heat; oxygen is taken from the nitric acid. When the mass is dry, expose it to a red heat for a few moments in a platinum crucible. The resulting substance is the variety called pyrophosphoric acid. If it be dissolved in water, and the solution laid by for some days, it is converted into phosphoric acid, although not the slightest change has been produced in the elements or their ratio.

Another process, less tedious, but not so safe without great caution, is to throw bits of phosphorus, not exceeding the size of small shot, one by one, into warm nitric acid, waiting each time until the effervescence cease. The phosphorus should not exceed one twelfth of the weight of the nitric acid: the former takes oxygen from the latter. Should the chemical action become violent, the vessel must be immersed in cold water. When the solution is complete, it must be evaporated to dryness, heated to redness in a platinum crucible, and treated as before.

A much more economical method of preparing phosphoric acid in the large way, when the ultimate object is the preparation of phosphorus, or when the acid is not required to be chemically pure, is the following:— Diffuse 20 pounds of powdered white bone ashes in 20 gallons of boiling water; gradually add 10 pounds of sulphuric acid diluted with 10 pounds of water, and keep the mixture stirring until all apparent action cease. Throw the whole into a cotton filtering bag, and occasionally press the sides of the bag so as to agitate the mass, and let 10 gallons more of water run through to wash out the acid. Neutralise the acid liquor with carbonate of ammonia; and when it clears, decant

and evaporate in a leaden boiler to a small quantity. Pour this matter, while hot, into a thin glass balloon, and place it on sand in a reverberatory furnace. Continue the heat until the bottom of the balloon is red. A hard, colourless, transparent phosphoric glass will remain, which, by breaking the balloon, may be easily detached.* This is pyrophosphoric acid, which, by being dissolved in water, and laid by for some days, becomes phosphoric acid.

From all that has been ascertained on this subject, it would appear that phosphoric acid is only known as existing in the liquid state. If it be evaporated, and heated to such a temperature as may be judged capable of expelling the chief part of the water, it is changed into pyrophosphoric acid: and the same change takes place when the acid exists in a salt combined with an alkali. Although between phosphoric and pyrophosphoric acid there is no known difference of composition, the properties of each are essentially different. Pyrophosphoric acid produces, with oxide of silver, a white salt; phosphoric acid a yellow one: the former is a less energetic acid; it has less saturating power, and is even separated from its combinations by phosphoric acid. This is another proof of the position laid down in other parts of this volume, that bodies of the same composition with regard to relative quantity and identity of elements, may be quite different as to properties, in consequence of some unknown difference in the manner in which the constituents are combined. The name pyrophosphoric acid is given to this substance, to indicate that it owes its origin to the action of fire on phosphoric acid.

When phosphorus is rapidly burnt in a large vessel filled with dry oxygen or common air, a white smoke arises, which soon condenses into white flakes: these are anhydrous pyrophosphoric acid. They are deli-

* Dr. B. Higgins, Minutes of a Philosophical Society, p. 252. If the acid is intended for making phosphorus, it will answer in the state of pyrophosphoric acid.

quescent, and, of course, readily soluble in water; they dissolve with a remarkable hissing noise. Indeed, such is the affinity of this acid for water, that even in its vitreous state it retains a small quantity which no heat will expel; for the compound of acid and water is volatilised at a bright red heat, if long enough continued. When pyrophosphoric acid is allowed to deliquesce, it is converted into phosphoric acid, owing to the length of time which elapses before it is liquefied.

Phosphorous acid. — Although it has been stated above that phosphorus burnt in the air affords pyrophosphoric acid, this is only true when phosphorus is heated to 148°, the point at which it takes fire, so as to burn rapidly and with full splendour, and when a fully sufficient supply of oxygen or common air had access to it. But if phosphorus be heated in a glass tube, the orifice of which is drawn out so small as greatly to obstruct the ingress of air, it will burn with a feeble greenish light, and become phosphorous acid. This is a white, powdery, volatile substance: it has a strong affinity for water, and will absorb it from the atmosphere, so as to deliquesce into a dense oil-like liquid. With one fifth of its weight of water it forms a hydrate, which is capable of crystallising. When the dry powder is heated in the open air, it takes fire, absorbs oxygen, and produces pyrophosphoric acid: but when heated in a close vessel, it is changed into the same from a different cause; for one portion is deoxidated, phosphorus sublimes, and its oxygen combines with the phosphorous acid. When hydrate of phosphorous acid is heated in close vessels, it affords pyrophosphoric acid, and phosphorus dissolved in hydrogen gas. If phosphorus be burnt in rarefied air, we obtain pyrophosphoric and and phosphorous acid, and a red substance supposed to be oxide of phosphorus.

The best mode of obtaining phosphorous acid is to pass the vapour of phosphorus through a glass tube, containing powdered corrosive sublimate; "a limpid fluid comes over, which must be mixed with water,

and the solution heated until it is of the thickness of syrup. It is a combination of water and pure phosphorous acid: it forms a white crystalline acid on cooling."—(*Davy.*) Corrosive sublimate is a compound of mercury and chlorine: the phosphorous vapour seizes on the chlorine, forms a limpid fluid chloride: the chloride of phosphorus is decomposed by the water; the hydrogen of the water combines with the chlorine, and forms muriatic acid; while the oxygen of the water unites with the phosphorus, and produces phosphorous acid. By heating, the muriatic acid and most of the water are expelled; the acid remains pure, and, if sufficiently concentrated, will crystallise in parallelopipedons.

Hypophosphorous acid. — Besides the foregoing two acids, there is this other, which contains a less ratio of oxygen than phosphorous acid. By combining phosphorus with lime, a compound is produced, which decomposes and is decomposed by water: the hydrogen forms a gaseous compound with a little phosphorus; and the oxygen unites with the remainder, and produces phosphoric and hypophosphorous acids, both of which combine with the lime; the former producing an insoluble, and the latter a soluble compound. The phosphate of lime being filtered off, the clear liquor must be mixed with dilute sulphuric acid, which, having a greater affinity for lime, will detach the hypophosphorous acid. The most remarkable feature in the history of this acid is, that all its combinations with alkalies and earths are soluble in water.

With regard to the ratio in which phosphorus and oxygen combine to form the three compounds—phosphoric, phosphorous, and hypophosphorous acids—there has been much discordance amongst the statements of chemists. The following represents the latest results, the elements being represented in parts by weight: —

	Phosphorus.		Ox.
Hypophosphorous acid consists of	4	combined with	1
Phosphorous acid - - -	4	- -	3
Phosphoric acid - - -	4	- -	5

Phosphuretted and *perphosphuretted hydrogen.* — By heating phosphorus in hydrogen, a solution of a small portion only is effected. There are two compounds, consisting of these elements in different proportions: they are commonly called phosphuretted hydrogen, and perphosphuretted hydrogen. They may both be formed from a combination of phosphorus and lime, called phosphate of lime, which is to be prepared by heating small bits of well-burnt lime in the middle of a long earthenware tube, sealed at one end, and having a piece of phosphorus kept cold at the sealed end, while the middle part is heated across a chafing-dish of burning charcoal. When the lime is red-hot, the end containing the phosphorus must be heated so as to convert it into vapour; this, by passing through the lime, will be absorbed, and will form a brown substance, which is phosphuret of lime. It is a troublesome and difficult process: if the object be merely to procure a spontaneously combustible gas from the phosphuret of lime, it may be accomplished with much less difficulty. Throw a piece of phosphorus into a cold crucible; and having heated some coarsely powdered roche-lime in another crucible to redness, pour it suddenly over the phosphorus, so as to cover it to the depth of two or three inches. There will be considerable inflammation, which may be checked by instantly filling up the crucible with sand. When the crucible is cold, the matter must be hastily taken out, and the brownest portions put up for use into a bottle to be well stopped.

When this substance is thrown into a glass of water, an instantaneous decomposition of a part of the water commences, which goes on for a length of time. Some hydrogen is evolved; but the chief part of the hydrogen combines with as much phosphorus as forms perphosphuretted hydrogen; and each bubble of this gas, on reaching the surface, spontaneously catches fire by intermixture with the oxygen of the air. A small cloud of white smoke, in the form of a ring, ascends from each bubble, widening as it rises, and mantling in a

singular and beautiful manner. This smoke is white, because it contains solid pyrophosphoric acid in a state of minute division. If the glass of water be introduced under a bell glass of oxygen or chlorine, the combustion of the gas is more brilliant: with the former gas the flame is white, with the latter greenish: but in either case there should be but very little of the phosphuret of lime, as the gas, when mixed with oxygen or chlorine, burns with violence. The oxygen of the water decomposed by the phosphuret of lime also combines with phosphorus, and forms phosphoric and hypophosphorous acids.

If pure perphosphuretted hydrogen is to be collected, it should be generated in a very small retort, filled to the top of the beak with water acidulated by muriatic acid: two or three lumps of phosphuret of lime must then be thrown in at the beak; and, as they sink, the beak must be plunged in the mercurial pneumatic trough. Gas will be formed, which should be collected in jars, filled with and preserved over mercury. Much should never be kept in one vessel; for there is risk of accidental intermixture with common air, which would cause the explosion of the gas.

When phosphuretted hydrogen is exposed to the light of the sun, or is allowed to remain for some time in vessels, no matter whether over water or mercury, except that in the latter case the change is produced much more slowly, the gas parts with a third of its phosphorus, and is converted into the same volume of *phosphuretted hydrogen.* This gas is not spontaneously explosive or combustible when mixed with common air or oxygen; but, if let into chlorine, it burns spontaneously. A very remarkable property of this gas is, that, when mixed with oxygen, rarefaction causes them to explode, as condensation produces explosion in other mixed gases; or the mixture will detonate by the electric spark, or by being heated to 300°. It may be here observed, that phosphuret of lime, if acted on by concentrated muriatic acid, evolves phosphuretted hy-

drogen; but if the acid is diluted, perphosphuretted hydrogen is the result. According to Thomson, 100 parts by weight of hydrogen combine with 16 of phosphorus, to form perphosphuretted hydrogen, and with 10·666 to form phosphuretted hydrogen.

Chlorides of phosphorus. — A compound of chlorine and phosphorus may be formed by passing the vapour of phosphorus through powdered corrosive sublimate. The latter, which is a compound of chlorine and mercury, is decomposed; its chlorine combines with the phosphorus, and forms a fluid as clear and colourless as water; this is chloride of phosphorus. It is not in its own nature acid; but when acted on by water, it becomes acid in the manner already described. If exposed to the air, it evaporates in smoke for the most part, but leaves a little phosphorus, which speedily burns. Its vapour burns at the candle.

Perchloride of phosphorus may be formed by introducing chlorine into a receiver previously exhausted of air, and containing phosphorus. "The phosphorus takes fire, and burns with a pale flame, throwing off sparks; and a white substance rises and condenses on the sides of the receiver." — (*Davy.*) This is a snow-white powder; it is very volatile, and evaporates at a heat below 212°; under pressure it may be fused, and it then crystallises into transparent prisms. It acts violently on water, and decomposes it: the oxygen and phosphorus form phosphoric acid, and the hydrogen and chlorine produce muriatic acid. It is analagous to an acid in many of its properties; its vapour reddens dry litmus paper.— (*Davy.*)

Phosphuret of sulphur. — Phosphorus and sulphur combine in various proportions, but the exact ratios are not known. The combination, if effected by heat, sometimes takes place with combustion and explosion. Phosphurets of sulphur are often used for obtaining instantaneous light: a sulphur match is dipped in the compound, and then rubbed on a piece of cork, which produces immediate combustion. A better contrivance

is the following: — Throw a bit of phosphorus into a small phial, kindle it, and allow it to burn for about two seconds; then extinguish it by corking the bottle. The substance in the phial is now somewhat red; it is supposed by some to be an oxide of phosphorus: it is so combustible, that it spontaneously takes fire in the air. If a sulphur match be dipped into it, a particle adheres to the match, and inflames on drawing the match out. I believe the following to be the theory of the process:—The phosphorus continually deprives the air in the phial of its oxygen; it is, therefore, continually in an atmosphere of azote, and it is thus prevented from burning. When the match draws out a particle, the latter takes fire as soon as it is brought out of the atmosphere of azote into common air; but the remainder of the phosphorus is protected from catching fire by the azote which surrounds it.

Section XI.

The substance called fluorine has never yet been obtained in a distinct form; the assumption of its separate existence may, therefore, be considered an hypothesis, though supported by the strongest analogies. Provisionally, a name has been given to it: it exists in the mineral called *fluor* spar; and is called *fluorine*. Fluor spar is otherwise called Derbyshire spar, or fluate of lime; but its proper name is *fluoride of calcium*. If some of this mineral in powder be distilled with strong sulphuric acid, from a leaden retort, into a leaden receiver kept cold with ice, "an intensely active fluid is produced. It has the appearance of sulphuric acid, but it is much more volatile. When applied to the skin, it instantly disorganises it, and produces very painful wounds. When it is dropped into water, a hissing noise is produced, with much heat, and an acid fluid is formed." — (*Davy.*)

This substance is called *hydrofluoric acid*, because it is supposed to consist of fluorine as a base, combined with hydrogen, to form the acid in the same manner as hydrogen acidifies or is acidified by chlorine. Hydrofluoric acid, thus prepared, contains no water; yet it cannot be obtained by distilling fluor spar with sulphuric acid, unless the latter contain water. The reason is, that hydrogen is necessary to the existence of hydrofluoric acid: the water is, therefore, decomposed; and while its hydrogen unites to fluorine, its oxygen combines with the basis of the lime present in fluor spar, which basis is the metal calcium. Such are the opinions which were supported by sir H. Davy, and first suggested by M. Ampere.

But a different view has been taken by MM. Gay-Lussac and Thenard, of the nature of fluor spar, and of the changes which take place during its decomposition. It has been supposed, that it is composed of lime united to an acid, to which the name fluoric has been given, consisting of a base, which may be called fluorine, and oxygen. If sulphuric acid be poured on this compound, it seizes on the lime, and detaches fluoric acid. Were it objected to this theory, that the fluor spar is not decomposed by anhydrous sulphuric acid, the answer would be, that fluoric acid cannot exist without water; and as water cannot be supplied by an acid which does not contain it, neither can that acid separate fluoric acid from fluor spar. But there is another fact which is not so easy of explanation: although anhydrous sulphuric acid does not decompose fluor spar, anhydrous muriatic acid does, and hydrofluoric acid gas is evolved. But this phenomenon becomes easy of explanation, on the hypothesis of Davy and Ampere, if it be admitted, with these philosophers, that to form the acid in question, fluorine combines with hydrogen instead of oxygen; that the acid can exist without water; and that fluor spar is a compound of fluorine and the metal called calcium. Muriatic acid consists of chlorine and hydrogen: if this compound be made to act on a compound of fluorine

and calcium, a double decomposition takes place; the chlorine combines with the calcium; and the hydrogen combines with the fluorine, forming hydrofluoric acid. We therefore, on this view, are able to assign the reason that, in order to decompose fluor spar, there must be water in the sulphuric acid, although there need be none in the muriatic; for it is hydrogen, not oxygen, that is required.

According to this view, which is now generally admitted, fluor spar is a fluoride of calcium, and not a fluate of lime, as the other hypothesis supposes: and hydrofluoric acid contains neither water nor oxygen; as, indeed, has been shown experimentally by Davy.

Hydrofluoric acid smokes in the air; it discharges fumes of an acid, penetrating, and suffocating nature; it is so volatile, that it can with difficulty be prevented from escaping; and so universal and energetic is its agency, that it is not easy to find an available material for confining it; bottles of lead or silver, with close stoppers, succeed. When anhydrous, its specific gravity is 1·06: but it possesses the property of having its density increased by the addition of water, which is a lighter liquid: it may be thus brought to the specific gravity of 1·25, considerable heat being at the same time developed. It reddens vegetable blues. In smell it resembles muriatic acid. It is most destructive to life.

By means of the powerful decomposing agency of galvanism, sir H. Davy endeavoured to resolve this acid into its constituents. But he could only produce an exceedingly small quantity of a combustible gas, which he conceived to be hydrogen; and of a chocolate-coloured powder, which corroded the platinum wire round which it collected, and which must have consisted of a constituent of the acid and platinum.

SECTION XII.

Flint had, for a length of time, been supposed to be an earth, analogous in composition to the other earths. When the metallic nature of the earths in general was in progress of being ascertained, it was naturally expected that silica, or the matter of flint, would also prove to be a metallic oxide. Experiment, however, failed to disclose such a composition; on the contrary, it has been shown that, as far as investigation has been able to reach, its base is of a nature very different from metallic, and agrees with a distinct class of bodies. It may be obtained by the following process:—

Let fluor or Derbyshire spar, and glass, (one of the constituents of glass is flint,) both in powder, be mixed with strong sulphuric acid, and heated in a glass retort; a gas arises, which, after it has expelled all the common air, may be collected in the usual manner over mercury: let a piece of metallic potassium be heated in this gas until it takes fire. After the combustion, the potassium will be found converted into a brown matter, which, when thrown into water, decomposes it, and evolves hydrogen; for it is a compound of the base of silica united with potassium, the latter of which takes up the oxygen of the water, and the former combines with a portion of the hydrogen. The brown powder must be washed with large and frequent effusions of water, and dried. This is a compound of hydrogen, and the base of flint: if it be heated in the air, the hydrogen burns; if it be heated in a close vessel, the hydrogen is expelled, and the pure basis of flint remains: it is called *silicon*: it very much resembles boron in its appearance, and in its relations to other matter.

Silica, or Silicic acid.—It is silicon, that, when combined with oxygen, forms the substance to which the

several names silica, flint, quartz, rock crystal, &c. have been given. But the compound, instead of being an earth, turns out to be an acid: and to obtain it in the state of an acid, no such difficult process as that just described need be had recourse to: all that need be done, is to heat a piece of flint red-hot; throw it into water, to make it pulverisable; then reduce it to a fine powder, and melt it with dry carbonate of potash in a crucible. When cold, throw it into dilute muriatic acid; filter, and evaporate the solution to dryness. Wash this powder, first with dilute muriatic acid, and then frequently with water; and then dry it. This is silicic acid: it is a gritty, white, tasteless powder.

It neither has an acid taste, nor reddens vegetable blues; it manifests its acid properties by combining with alkalies, earths, and metallic oxides, in definite quantities, and with such force of affinity, that it is not easy to decompose the compounds. Flint glass is a salt of this kind; it is a silicate of soda and lead. It must be admitted, however, that its acid powers are not very decided.

Silicon does not easily combine with gaseous oxygen, although it does readily with oxygen solidified in certain combinations. Thus, if mixed with carbonate of potash, and heated very moderately, it burns, and takes oxygen from the carbonic acid: the silicon becomes silicic acid, which remains in combination with the potash. Silica, or silicic acid, is composed of equal weights of silicon and oxygen.

Fluosilicic acid. — Hydrofluoric acid has the property, which no other acid possesses, not only of taking the silica from flint-glass, but decomposing it, and holding its silicon dissolved in the gaseous state. In this case the silica parts with its oxygen; the hydrofluoric acid loses its hydrogen: the former is reduced to the state of silicon, the latter to that of fluorine. The silicon and fluorine, in this nascent state, combine, and form an acid. It is difficult to determine which is the base and which the acidifier: but it is known that the com-

pound is an acid, and the name of *fluosilicic* acid has been given to it. It may be readily obtained by mixing glass and fluor spar, both in powder, with strong sulphuric acid, in a glass or leaden retort, and applying heat; fluosilicic acid gas is discharged abundantly. The theory of its formation is obvious from the foregoing observations.

This gas is very heavy: 100 cubic inches of it weigh 110·77 grains; hence its specific gravity is 3·631.—(*Davy.*) Dr. Thomson estimates it 3·6. It produces white fumes when it is diffused in the atmosphere.

This gas, when brought in contact with water, is partially decomposed by and decomposes it. Oxygen passes from the water to part of the silicon, forming silica, which is deposited in the state of gelatinous hydrate: and the hydrogen of the water combines with the remaining unaltered fluosilicic acid, and converts it into a totally different acid, called *hydrofluosilicic* acid. This acid enters into combination with many bases: its taste is sour. The hydrate of silica, obtained in the process, is soluble in water.

The action of hydrofluoric acid on silicon, even when contained in glass, has been made available for the purpose of etching on glass. The easiest mode is to coat the glass with a varnish made of spirit of turpentine and wax, on which, when dry, the drawing or writing is to be traced with a needle, cutting through the varnish down to the glass. A margin of wax being then raised round the glass, the hydrofluoric acid, diluted with water, is to be poured on: in a few minutes the whole may be plunged in water. The varnish being removed, it will be found that the lines traced by the needle are corroded into the glass; and beautiful etchings are often thus executed.

SECTION XIII.

The substance called borax has long been used in the arts and in medicine; but it is only of late years that any thing is accurately known of its composition. If borax, which had been melted in the fire and then powdered, be heated intensely with a tenth of its weight of fine powdered charcoal, in a gun-barrel closed at one end, a black powder is obtained, which must be several times washed with hot water, then with muriatic acid, and finally with water again. The resulting powder, when dried, is of a blackish olive colour: it contains some charcoal: but the other ingredient is *boron*. In this state it is sufficiently pure for ordinary experiments: to obtain it perfectly pure, boracic acid must be decomposed by potassium. Pure boron is an opaque, brownish olive powder, infusible, and not volatile in any temperature to which it has as yet been exposed. It neither dissolves in nor acts upon water: it bears all degrees of temperature, under 600°, without change; at about that heat it takes fire, and combines with oxygen. If burnt in oxygen, it throws off bright scintillations, and is converted into a combination of boron with oxygen. This compound possesses the properties of an acid: it is called *boracic acid*, and, when combined with soda, forms the borax of commerce.

Boracic acid. — But it is not by this process that boracic acid is procured for chemical purposes. Borax is a compound of boracic acid and the alkali called soda: this salt is to be dissolved in boiling water, and dilute sulphuric acid is to be added; it combines with the soda, and detaches the boracic acid, which, on the cooling of the liquor, separates in scaly crystals: these, washed with cold water, are boracic acid. It is by no means a powerful acid; and it even evinces qualities of rather an equivocal nature with regard to acidity; thus its taste

is scarcely, if at all, sour: although it reddens litmus paper, it acts like an alkali on paper stained with the dye-stuff called turmeric. The colour of turmeric paper is yellow; when acted on by an alkali it is changed to brown: it is hence used as a test of alkalinity; yet boracic acid renders it brown. But this substance manifests acidity, by combining with alkalies, earths, and metals. It dissolves in rectified spirit; and if the solution be set on fire, it burns with a green flame: if exposed to heat, it parts with its water of crystallisation, amounting to 43 per cent.: it melts, and then bears any degree of heat without further change. When cold, it is found converted into a perfectly colourless, transparent glass, which remains so, if it be preserved from the air; but loses its transparency, if exposed, by the re-absorption of the water which it had lost during the heating. Borax itself, when heated, melts into a perfectly clear glass, which is the basis of some artificial gems that possess considerable beauty. Borax communicates its own fusible nature to other bodies, and hence is used as a *flux*. Boracic acid is the only known combination of boron with oxygen: it consists of one part of boron combined with two of oxygen.

Fluoboric acid.—Fluorine and boron have an affinity, and are capable of combining; the result is an acid, which exists in the gaseous state. If fluoride of calcium (fluor spar) and boracic acid, which had been melted to a glass, so as to expel its water, be heated together in an iron tube, both having been reduced to powder and well mixed, there will be a double decomposition: fluorine will forsake the calcium; the calcium will take oxygen from some of the boracic acid: the latter will be converted into boron; but the calcium, by combining with the oxygen, will form lime, and this will unite with the remainder of the boracic acid: meanwhile the boron and fluorine combine, and form a transparent and colourless gaseous acid, which is evolved, and which has obtained the name of *fluoboric acid.* It is anhydrous. Its smell resembles that of muriatic acid.

In this case, either boron is acidified by fluorine, or fluorine by boron: but, perhaps, the truth may be, that neither acts the part of the acidifier more than the other. According to the theory of Gay-Lussac and Thenard, a different explanation mnst be given. Fluor spar must then be considered a fluate of lime,—that is, a combination of lime with fluoric acid; and fluoric acid must be viewed as a compound of fluorine and oxygen: when heated with boracic acid, the latter decomposes the fluate of lime; one part of the boracic acid combines with the lime, and the other part combines with the fluoric acid, now detached, and forms a gas, consisting of fluoric and boracic acids, the name of which must therefore be, not fluoboric acid, but *fluoroboracic* acid. According to this theory, we should expect that, if the acid gas be passed into water, we should obtain a solution of fluoric and boracic acids; and this is precisely what happens, for boracic acid actually crystallises. But the fact can be equally well explained, by supposing that fluorine and boron compose the acid gas: the gas, when passed into water, decomposes a portion of that liquid: its oxygen passes to the boron, and produces boracic acid; while the hydrogen goes to the fluorine, forming hydrofluoric acid. This explanation is the one now generally received.

Fluoboric acid gas is not prepared for use by the process given above; the best method is to distil a mixture of fluor spar and borax, both in powder, with sulphuric acid: a glass retort will answer for this purpose, as it is not acted on by fluoboric acid. The spar should be quite free from flinty matter; for if it contain it, as it generally does, the silicon would be converted into fluosilicic acid. The gas must be collected over mercury.

Fluoboric acid gas contains no water; yet it has so powerful an affinity for water, that when allowed to escape into the air, or into a gas containing moisture, there is an immediate condensation of the vapour into visible fumes: this acid is, therefore, sometimes used as a test of the presence of moisture in gases. Its specific gravity is 2·362. The fumes which it produces in the

air are white, and almost opaque. It is absorbed rapidly and largely by water, the volume absorbed at 50° being 700 times greater than that of the water: the solution is of specific gravity 1·77. During this absorption, some boracic acid crystallises, and dissolves again as the liquid approaches saturation. The taste is powerfully acid.

Section XIV.

To an ordinary observer it might appear, that all metals are essentially the same, and that their difference of colour and other properties may be owing to a tinge and character given to them by adventitious circumstances, or by a trifling admixture of other substances. The opinion is natural, and was once entertained by most of the chemists of that day; or, as they were then called, alchemists: and as gold was the most valuable of all metals, and was considered as the pure basis of all the rest, their efforts were directed to the separation of the substance, whatever it might be, the presence of which prevented lead and other base metals from being gold. It is scarcely necessary to observe, that these efforts failed; the modern chemists, believing the thing to be impossible, have come to the matter of fact conclusion, that when metals are of different colours, degrees of hardness, strength, lustre, brittleness, &c., they are of different natures.

Gold. — This is the most valuable of all metals. In a state of purity it is not generally known, as the metal is not commonly met otherwise than alloyed with copper. The gold coin of Great Britain is a mixture of gold, copper, and silver. The constitution of the coin was first determined by law in the reign of Edward I.: 22 parts or carats of fine gold, 1 of copper, and 1 of silver, at present constitute sterling gold; or it may consist of 22 parts of fine gold and 2 of copper. The mint price of this gold, that is, the standard value

at which it issues, is 3*l.* 17*s.* 10½*d.* per ounce: and a troy pound of it, formerly coined into 44½ guineas, is now coined into 46 sovereigns, and 14*s.* 6*d.* over, each sovereign weighing 123¼ grains, or more exactly 123·274. This is called *sterling* gold; but *standard* gold does not mean exactly the same. The latter term has more immediate reference to the manufacture of gold utensils, and takes greater latitude of composition. Standard gold has two extremes: it may be sterling, that is, 22 gold + 2 copper; or it may be 18 gold + 6 copper. Articles sent to Goldsmith's Hall to be marked will obtain the mark representing either of these qualities. Should the article sent profess to be sterling, and prove on assay not to be so rich in gold, it will be broken, and the mark refused. Should it profess to be 18 carats fine (that is, gold 18 + copper 6), while it is really richer, or sterling, or even virgin gold, it will be marked as 18 fine. Any article below 18 carats will not be marked; and pure gold will be marked as 11 carats. Silver may be substituted for copper; its effect is to produce *green* gold, as it is called.

The reason of adding these other metals is, that pure gold is not the most serviceable state of the metal: a mixture of gold and a very small quantity of copper is much harder than pure gold, and will wear much better. It may be here observed, that when any metal is melted, and combined with another or several metals, the compound metal is called *alloy.* The property of being extended by mechanical force, as by hammering, is called *malleability.* In the chapter on cohesion, many examples of the malleability of gold have been given. The *ductility* of gold, or that property which permits it to be drawn out into thin wires, is considerable: a wire of only $\frac{1}{10}$th of an inch in diameter will support a weight of 500 pounds without breaking; this property is called *tenacity,* and it belongs to gold in an eminent degree; but it is known that the process of drawing a metal into wire enhances its natural tenacity. It requires a heat very little higher than copper to melt it,

much higher than silver, and greatly higher than zinc, lead, and tin; but by far lower than iron. It may be kept at a very high heat for almost any length of time unaltered: Kunkel kept gold in a glass-house furnace for nearly eight months, during which it neither lost any weight, nor appeared changed. The highest temperature that can be excited is found, however, to volatilise a little of it.* If exposed to the most intense heat of a powerful burning glass, its surface becomes purple, owing to the absorption of a little oxygen by the metal from the atmosphere; and it may be actually burned in the flame of hydrogen urged by a stream of oxygen, and converted into a purple oxide. Electricity does the same.

When 100 grains or parts of gold combine with 4 of oxygen, an oxide is produced: but this oxide does not contain the largest quantity of oxygen that can be combined with gold; for these 104 grains, in a short time, undergo decomposition; one third robs the other two thirds of their proportion of oxygen, and the part thus deprived is reduced to its original state of metallic gold. The gold, thus deprived of its oxygen, weighs $69\frac{1}{3}$ grains; the oxygen of this quantity, amounting to $2\frac{2}{3}$ grains, is, therefore, transferred to the remaining $34\frac{2}{3}$ parts of oxide, which, already containing $1\frac{1}{3}$ grain of oxygen, will then contain 4 grains of oxygen in all: but this is the full quantity of oxygen which the original 104 grains of oxide held combined; and it is now contained in one third of that weight, or $34\frac{2}{3}$ grains. Hence, a new oxide is the result; and it must, therefore, contain three times as much oxygen as the original oxide. From these facts it is manifest, that gold combines with oxygen in two proportions: its protoxide is composed of 100 parts of gold, combined with 4 of oxygen; and its peroxide of 100 parts of gold united to 12 of oxygen.

Gold alloys with various other metals, as tin, lead,

* Brisson's Physical Principles, &c. p 209. Brisson gilt a piece of silver held a little above gold intensely heated by a burning lens.

copper, iron, mercury, &c.; the alloys being of more or less use. When any metal unites with mercury, it is said to *amalgamate;* and the compound is called an *amalgam:* but the distinction is absurd, and without practical use.

Gold is a little more than 19 times heavier than its bulk of water; its precise specific gravity, when pure, is 19·3.* Its hardness is between that of silver and tin. Notwithstanding its ductility, the smallest admixture of bismuth, lead, or antimony, renders it brittle; so little as $\frac{1}{1920}$th of either is sufficient to affect its ductility.

Gold is found, in nature, in the metallic state for the most part. When any metal occurs, in a state of nature, in its metallic form, it is said to be found in the *native state.* But native gold is seldom pure, being generally alloyed with a little silver or copper. It occurs in compact masses, or crystallised in cubes, prisms, octahedrons, or pyramids; or it is found in grains. It is found, in veins, in primitive mountains, although not of the oldest formation, accompanied by various stones and metallic ores.

Gold occurs in almost all parts of the world; and, although so generally, only in small quantities, unless in the warmer regions of the globe. Africa and America supply the chief European consumption. America produces, annually, 30,000 pounds' weight. About thirty-six years since, an immense fragment of rock tumbled from one of the highest mountains of Paraguay; and masses of gold, weighing from two to fifty pounds each, were picked out of it. In the cabinet of the count d'Ons-en-Bray there was a specimen of native gold, which weighed sixteen pounds.—(*Brisson.*) It is found in grains, in the sands of rivers, in various parts of Africa, America, and even Europe. Cramer says, that "there is hardly any gravel, in the nature of things, that does not contain gold in it."—(*Docimasia.*) Near Pamplona, in South America, single labourers have collected 200*l.* worth in one day; and in some

* It has been stated by Mr. Mills, that Irish gold is but 19.

parts, amongst the grains, lumps weighing 72 and 132 ounces. In certain rivers in Scotland, gold dust has been found. At the coronation of Charles I., medals were made of this gold, with this inscription round the edge, *Ex auro ut in Scotia reperitur.* And, in 1539, a coinage of native gold was issued in Scotland.

In Ireland, county of Wicklow, seven miles west of Arklow, about the year 1770, there was an old schoolmaster, who used frequently to entertain his neighbours with accounts of the richness of their valley in gold; and his practice was to go out in the night to search for the treasure. For this he was generally accounted insane. But, in some years after, bits of gold were found in a mountain stream, by various persons; and, in 1796, a piece weighing about half an ounce. The news of this having circulated amongst the peasantry, such an infatuation took possession of the minds of the people, that every other sort of employment, save that of acquiring wealth by the short process of picking it up out of the streams, was abandoned; and hundreds of human figures were to be seen bending over the waters, and scrutinising every object there to be seen. In this way, during six weeks, no less than 800 ounces of gold were found, which sold for 3*l.* 15*s.* per ounce, or 3000*l.* Most of the gold was found in grains; many pieces weighed between two and three ounces; there was one of five ounces, and one of twenty-two. It contained about 6 per cent. of silver. Government soon undertook the works; but the amount of gold found, while superintended by the appointed directors, was only 3675*l.* It then appeared, that there was no regular vein in the mountain, and that these fragments had probably existed in a part of the mountain which time had mouldered away, and which left its more permanent treasure as the only monument of its ancient existence. The works were at length discontinued.

In Croatia, in the sands of the Drave, gold to the value of about 1600 ducats is annually found by the peasantry.

Gold is said to have been detected in vegetable ashes and in garden manure. It enters into various combinations; we have its combination with chlorine, iodine, bromine, sulphur, and phosphorus. It dissolves with effervescence in a mixture of nitric and muriatic acids: the result is chloride of gold. If peroxide of gold be dissolved in muriatic acid, and precipitated by ammonia, a powder is obtained, which detonates even by being rubbed.

Silver. — The metal next in esteem to gold, of those that are generally known, is *silver*. This is a soft metal, and possesses great malleability: it may be beaten into leaves so thin as $\frac{1}{100000}$th of an inch; yet this is almost three times thicker than gold leaf. It may be drawn out into wires thinner than the human hair; hence its ductility is next to that of gold. Its tenacity is such, that a wire one tenth of an inch in diameter will support a weight of 270 pounds. Its tenacity is, therefore, not much greater than half that of gold: but silver is a little harder. Its specific gravity is 10·474. In point of brilliancy, it exceeds all metals except steel. It melts at a full red heat; and by a fierce and long continued fire, it may be made to boil and evaporate away altogether. In the greatest ordinary heats, as that of a glass-house furnace, it loses but little weight, and that little slowly.

If kept for a long time melted, it absorbs oxygen from the atmosphere, and forms a brown oxide, 100 parts of silver combining with 7·272 of oxygen. Dr. Faraday has discovered an oxide that consists of 4·848 parts of oxygen combined with 100 of silver; that is, two-thirds of the quantity of oxygen contained in the brown oxide. The singular fact has been ascertained, that silver in fusion absorbs oxygen, which, on solidifying, it parts with: and Gay-Lussac says, that it thus gives out twenty-two times its own volume, and that the presence of a very little copper destroys this property. Silver alloys with gold, iron, lead, tin, quicksilver, &c.: it unites also with copper, and forms an alloy which, like that of gold with copper, is harder

than the pure metal; and hence copper is used in the silver coin of the kingdom, in the ratio of 37 parts of fine silver to 3 parts of copper. A remarkable circumstance attends the combination of these two metals, which illustrates the principle that bodies do not unite in every proportion, but in determinate proportions: if the two metals be kept melted together for some time, and allowed to cool, two strata will be found, one lying over the other, and not adhering; neither stratum, however, is pure, for each metal contains a portion of the other that portion being the saturating quantity.

One pound of standard silver is coined into 66 shillings: it was formerly 62 shillings — (*Watson*): the mint price of silver is, therefore, 5*s*. 6*d*. per ounce at present.

This metal occurs in the native state, and alloyed with a variety of other metals and substances. It is found in all parts of the world. In 1750, a mass of native silver was taken from a mine near Freyburg, which weighed upwards of 140 pounds: and in 1748, a mass, a part of which was ore, was discovered, which produced 44,000 pounds of silver. The lead ores for the most part contain some silver: it is said, that in the lead ore of a mine in the county Antrim, one-thirtieth of the whole weight of metallic lead obtained is silver. The Cumberland lead ore affords 17 ounces of silver from a ton of lead. But a mine in Yorkshire, for every ton of lead, afforded 230 ounces of silver. The lead mines in Cardiganshire produced at one time 2000*l*. worth of silver per month. In 1604, 3000 ounces of Welsh silver were coined at the Tower. We are informed by Humboldt, that the silver mines of Mexico and Peru, in the space of three centuries, have produced 316,023,883 pounds' weight of silver. These mines afford many times more silver annually, than all the mines in Europe collectively. The silver mines of Kongsberg, in Norway, in one year (1769), produced 79,000*l*.

Silver combines with chlorine, iodine, bromine, sulphur, selenium, and phosphorus. It dissolves readily in dilute nitric acid, and may be precipitated in the metallic state, although not perfectly pure, by immersion of a plate of copper: but perfectly pure, and in fine powder, by pouring into it a solution of green sulphate of iron. By digestion in liquid ammonia, oxide of silver acquires the property of detonating when struck or rubbed.

Iron.—We now come to consider a metal with which none can compare in point of real utility, and fortunately of abundance. Iron is found in almost every mineral production. It is much harder than either of the two preceding metals. Its specific gravity is from 7· to 7·84; and it is, therefore, the lightest of all the useful metals except tin. It may be drawn out into wires of great fineness: a wire one tenth of an inch in diameter will support a weight of 450 pounds: hence its tenacity is a little less than that of gold. It is one of the few metals which the magnet attracts; and it readily acquires magnetic properties, which, however, are not permanent.* To melt iron requires a very intense heat, much higher than either of the preceding metals, and, indeed, nearly the highest that can be excited in furnaces. When raised to a yellow heat, it becomes very soft, and may then be hammered out into any shape. When the heat is raised to whiteness, it grows so soft as to suffer even a commencement of fusion: for if two pieces be laid in contact at this temperature, and struck, they unite and form one, the junction being as solid as any other part of the iron. This property of uniting, by hammering at a high heat, is called *welding*. Iron is a very combustible metal; if thrown into a common coal fire, in a state of filings, it burns with brilliant scintillations: and a very thin iron wire burns with scintillation in the external flame of a candle. Its vivid combustion in oxygen was

* Permanently magnetic bars are made of steel.

described in a former chapter. During the combustion, the iron melts and forms into drops, which at length fall down. This is protoxide of iron: to form it, every 100 parts of the metal combine with 28·572 of oxygen. If the protoxide be exposed to a red heat for some hours, it absorbs half as much more oxygen, and forms the peroxide, consisting of 100 metal and 42·857 oxygen: and if the peroxide be heated to whiteness, it will give off the 14·285 parts of oxygen, and will be reduced to the state of protoxide. The colour of the protoxide is black; that of the peroxide is red: but, according to Gay-Lussac and Thenard (*Traité Elementaire,* trois. edit. ii. 87.), there is an intermediate oxide obtainable by passing steam over iron wire at a red heat. The British chemists reject this oxide. I have reasons for believing that it exists: for I have obtained compounds which seem not to contain either of the admitted oxides.

Iron, in the purest state in which it occurs in commerce, is called *wrought iron.* If pieces of wrought iron be laid one over another, with intermediate layers of charcoal, and kept at an intense heat for several days, a combination of iron and charcoal will take place, and the result will be *steel,* which every one knows is capable of being made much harder than iron: it is also more sonorous, tenacious, elastic, and ductile, than iron. It is capable of becoming a permanent magnet: iron acquires only a fugitive power. The ratio of carbon combined with iron so as to form *cast steel* is 99 parts of iron to 1 of carbon. But these are not the only proportions in which they unite: *white cast* iron consists of 100 parts of iron, combined with 5·26 of carbon: this kind is brittle, and so very hard that it cannot be cut with a file. *Black cast* iron is composed of 100 parts of iron, united to 7·066 of carbon: it is fusible, and much softer than the preceding; the quality used for castings is of this nature nearly. These estimates are taken from Thomson's experiments, and they agree pretty nearly with those of Mr. Mushet.

Thus, the greater the ratio of carbon to iron, the more fusible the compound becomes; and the greater the ratio of carbon, within certain limits, the harder the compound becomes: but beyond these limits it is rendered softer.

The relation of these three compounds, with regard to the quantity of carbon which they contain, is illustrated by the fact, that if a slender rod of pure wrought iron be immersed in melted cast iron, it will come out converted into steel, because some of the carbon has been absorbed by it from the cast iron. Wrought iron may be converted into steel by ignition in carburetted hydrogen.

It has been already stated, that the diamond possesses the property of converting wrought iron into steel, because the diamond is carbon.

Iron is found in all parts of the world. There is scarcely a stone, or a particle of soil, in which it may not be detected; it exists even in plants, and in the human body. It occurs commonly in the state of oxide, more or less complicated with clay or stones, and other metals; it is thus found in veins, and disseminated in rocks. The sulphuret of iron, called pyrites, is a very common mineral. Iron also occurs in immense masses in such situations as have suggested the idea of their having fallen from the air; they have hence been called *meteoric iron*. Professor Pallas describes a block of this iron found on the top of a mountain in Siberia; it was said by the inhabitants to have fallen from the sky; it weighed 1680 Russian pounds.* In Croatia, a large red-hot mass of iron was actually seen to fall from the atmosphere: it is now in the imperial museum of Vienna: this occurred in 1751. In South America, a mass of meteoric iron was discovered many years since, which was estimated at 30 tons' weight. Another, found in Peru, weighed about 15 tons; its external surface was marked with singular impressions, resembling hands and feet, and the claws of birds. In

* Equal to 1533½ avoirdupois.

the desert of Zahra, there lies a vast mass of this kind of iron. In the Academy of Sciences at Petersburgh, there is a mass deposited, which weighs 1200 pounds. In 1620, a mass of iron fell from the atmosphere in the Mogul territory, which weighed a little more than 4 pounds.

It is very singular that these masses of iron lie in situations to which they could scarcely have been projected from any volcano; none such being found within a considerable distance of them, and no symptoms of an extinguished volcano having been discovered in the surrounding country. It is also a remarkable circumstance, that the iron in many cases is combined with another metal, nickel, which is always an ingredient in these masses, called meteoric stones, that have been actually seen falling from the air. Hence, it is no wonder that the belief of these masses of iron having fallen from the atmosphere has become prevalent. La Place has has even calculated, that they may have been projected from a volcano in the moon.

Iron, when heated in chlorine, burns with a red light, and forms a chloride. It combines with sulphur in five different proportions. It will be only necessary here to describe that which is frequently used for procuring sulphuretted hydrogen. There is some difficulty in preparing it in such a manner that no metallic iron shall remain unchanged: for, in proportion as there is metallic iron, hydrogen will be produced when the compound is acted on by dilute sulphuric acid. I have never failed in procuring sulphuret of iron good enough for common purposes, when I observed the following formula: — Mix 10 ounces of fine iron filings with 6 of flowers of sulphur: heat a crucible to a bright red, and, having removed it from the fire, throw in the mixture. A kind of combustion commences round the margin next the crucible, and this extends slowly to the centre, the ignition becoming more intense every moment. When it has reached the centre, the combination is complete, and the ignition begins to diminish. When

cold, the mass shrinks, and may be extricated from the crucible by mere inversion. It is a deep gray-coloured with a shade of purple.

Iron combines also with selenium, silicon, phosphorus, boron, and various metals.

Copper. — The metal, which in point of general utility ranks, perhaps, next to iron, is copper. Its peculiar red colour need not be described. Its specific gravity is very variable: on an average, it may be said that copper, after melting, is 8·9: by hammering it is increased; a specimen which, after melting, was but 7·242, became 9·020 by being hammered. — (*Watson's Essays*, iv. 57.) Copper is a very malleable metal: it may be beaten out into very thin leaves, by the same process as gold leaf is made, and in this state it is called *Dutch metal*. It melts at rather a lower heat than gold: at an intense heat, it boils and evaporates away in metallic fumes. When rubbed, it emits a smell. When heated in a hydrogen flame, urged by oxygen, it burns brilliantly, and emits a dazzling green light: a piece of copper, in a coal fire, tinges the blaze green; and even when melted, it emits a bluish green light. When exposed to air and moisture, it rusts into *verdigris*, but very slowly without moisture. When heated red-hot for some time, its surface saturates itself with oxygen, and a scale is formed, which is spontaneously detached when the metal cools: this is deutoxide of copper; and, to form it, 100 parts of copper combine with 25 of oxygen. The protoxide, procurable by a more complicated process, consists of 100 parts of copper, united to 12·5 parts of oxygen, which is half the former quantity. The peroxide is composed of 100 parts of copper, combined with 50 of oxygen.

When copper leaves are introduced into chlorine, the metal spontaneously takes fire, and a chloride is produced. If copper filings and sulphur be heated, a sudden and brilliant combustion takes place; and this happens even in a vacuum. The result is a sulphuret

of copper. Copper combines also with phosphorus, selenium, and iodine.

Copper is found in the native state in all parts of the world, although not in large quantities: but one very large mass of metallic copper is on record; it was found in Brazil, and weighed 2666 pounds. It occurs alloyed with other metals, or combined with oxygen and acids.

Lead is one of the softest and most fusible of the metals. It is easily rolled into sheets; but it does not admit of being beaten into leaves like gold, silver, and copper; nor does it allow itself to be drawn into very thin wire. Its specific gravity is 11·4. At a temperature between 600° and 612° it melts; at a higher heat, it boils and evaporates: at the heat of burning hydrogen, urged by oxygen, it burns with a bluish flame. When exposed to air while in fusion, and kept continually stirred, it absorbs oxygen, and is at length totally converted into an oxide. There are three oxides of lead: the protoxide consists of 100 parts of metal, combined with 7·692 of oxygen; the deutoxide, of 100 metal, with half as much more oxygen, or 11·538; the peroxide, of 100 metal, with twice as much oxygen as forms the protoxide, that is, 15·384. The protoxide is known in commerce as a yellow paint, under the name *massicot*, or, if it be semivitrified, *litharge*: the deutoxide is also a paint; its colour is a brilliant red, inclining to orange: its commercial name is *minium*, or *red lead*. The peroxide is of a deep, puce brown colour; its most remarkable property is, that, when triturated with sulphur, spontaneous combustion takes place. The peroxide may be formed by transmitting chlorine through water mixed with red lead: when the latter is dissolved, add potash; a powder falls, which is to be dried on blotting paper.

Lead is never found native. If protoxide of lead be exposed to a sufficient heat, it melts, and forms a beautiful glass, perfectly transparent, and almost colourless: by far the most common state in which it occurs

in nature, is mineralised by sulphur. The common name for sulphuret of lead is *galena:* it is abundantly found in all the quarters of the globe; most abundantly in secondary rocks, but often in primary.

Tin resembles lead in many of its properties. We speak familiarly of various implements and vessels said to be made of tin; but what is meant is tin-plate, or plates of iron coated on both sides with tin, which, in some degree, has penetrated the iron throughout. The use of tinning sheet iron is to prevent it from rusting, and the consequent destruction of the utensil; tin is much less perishable than iron when exposed to air and moisture. Tin is of a mellow silver colour: its softness is such, that it may readily be cut with an iron knife. It may be beaten out into leaves less than $\frac{1}{2000}$th of an inch thick. What is called tin-foil, however, contains a little lead. Tin melts at a much lower heat than lead; 440° is sufficient. Its specific gravity is 7·295. When intensely heated, and oxygen supplied, it burns with great brilliancy. When kept melted for some time at a low red heat, in contact with air, oxygen is absorbed, and a gray protoxide is produced. There are two oxides: the protoxide consists of 100 parts of tin combined with 13·793 of oxygen; and if the protoxide be considerably heated, it takes fire, burns like tinder, absorbs a new portion of oxygen, and forms the peroxide, consisting of 100 parts of tin and 27·586 of oxygen, or double the quantity in the protoxide.

This metal combines with chlorine, iodine, bromine, phosphorus, sulphur, and fluorine. It alloys with several metals. The coat of tinning which is given to the inside of copper vessels, is, in fact, a mixture of lead and tin; and the use of it is to prevent the copper from coming in contact with the food prepared in such a vessel, which might be otherwise impregnated with that poisonous metal. Although lead itself is a poisonous metal, it is singular that the presence of tin renders it innoxious; the reason of which is, that tin prevents the

lead from dissolving. Pewter is composed of lead and tin; and on account of the presence of the latter, the former is rendered safe. Tin generally occurs combined with oxygen, in a crystalline form, in veins traversing primitive rocks. It is found in many parts of Europe, and in all quarters of the globe. It does not appear that tin is ever found in the native state, unless we rely on the testimony of Matthesius. Cramer affirms, that "English tin is the best of all; for its ore is, of all tin ores, that which is less defiled with iron." The first exportation of tin from England took place 2200 years ago.

Zinc.—This metal, although entering into the composition of one of the best known of all metallic compounds, is, itself, very little known to the generality of persons who have not made these subjects their study: when combined with copper, it forms that useful substance, *brass*. Zinc is of a bluish white colour; its hue is intermediate between that of lead and tin. Its specific gravity is about 7, or very nearly the same as that of tin. When heated, it enters into fusion about 680°, or 700°: at a higher rate, it evaporates; and, if access of air be not permitted, it may be distilled over—by which process it is rendered purer than before, although it is not perfectly pure. When heated red-hot, with access of air, it takes fire, burns with an exceedingly beautiful greenish or bluish white flame, and is, at the same time, converted into the only oxide of zinc with which we are acquainted, consisting of 23·53 parts of oxygen, combined with 100 of metal. It is, when cold, a fine white powder, like flocks, and so light, that it was formerly called *philosophical wool* and *white nothing*. At common temperatures, zinc can be extended but little under the hammer; but, at a heat a little above that of boiling water, it may be rolled into thin sheets with facility, or drawn into wire, although it will not form thin wire. At a temperature midway between this heat and its melting point, it becomes so brittle, as to be easily reduced into a fine powder.

Zinc is found in all quarters of the globe: it occurs in Great Britain and Ireland, associated with lead: it is never found native, but is met in combination with oxygen, sulphur, &c. It combines with, and is set on fire by, chlorine: it enters into union with phosphorus, sulphur, selenium, iodine, and various metals.

Mercury.—However easily melted some of the preceding may be, there is one metal which exceeds them, and all others, in fusibility: this is quicksilver, or, as it is called by chemists, mercury: so fusible is it, that, without the aid of art, we never see it in any other state than that of a liquid. Yet, when mercury is reduced to a very low temperature, it freezes, or becomes solid; and then it may be cut with a knife, or beaten out a little by the hammer. Its malleability is, however, very limited. The freezing of mercury has been known to take place, in very cold climates, spontaneously, and without any artificial process: it was witnessed by Pallas, at Krasnojark. This metal, in freezing, contracts very much; hence the mercury of a thermometer does not indicate the true freezing point when it becomes solid. On such occasions, it has sunk 600° below freezing. Its freezing point is discovered by allowing a mass of frozen mercury to liquefy slowly when the air is very cold: during this process, a thermometer immersed in the mercury will steadily stand at about 40° below zero, which, of course, is the real freezing point. The temperature at which it boils and evaporates is 660° of Fahrenheit's thermometer. It may be readily distilled over. Its specific gravity at 60° is 13·568.

Mercury combines with oxygen in two proportions: to form the protoxide, chemists seem agreed that 100 parts of metal unite with 4 of oxygen; and, to form the peroxide, the same quantity of metal unites with twice as much oxygen, or 8. By keeping mercury at its boiling heat for a length of time, in contact with air or oxygen, its vapour combines with the oxygen, and forms the peroxide: but it is a very difficult matter to

obtain the protoxide in a state of purity. This metal is not altered by exposure to air, or moisture, or both. It combines with chlorine in two proportions: the chloride, commonly called *calomel*, consists of 100 parts of mercury, united to 18 of chlorine; the perchloride, called *corrosive sublimate*, of the same quantity of mercury, with 36 of chlorine: it is a violent poison. Mercury also combines with iodine, bromine, sulphur, and fluorine.

This metal occurs in the native state, or amalgamated with silver, or combined with sulphur, constituting cinnabar. It is produced in South America and Spain in great abundance. But, perhaps, the greatest quicksilver mine in the world is that of Idria, in Carniola. It has been at work for more than three centuries: its average produce, during four years, was about 366,000 pounds of mercury; it employs, in all, about 1000 men. The ore raised affords better than 8½ per cent. of metal: but mercury in the metallic state is found abundantly, sometimes issuing from the rock in a stream; and, in this way, 36 pounds have been collected in six hours.

Platinum. — This is a metal which, of all others, possesses properties the most useful for the construction of vessels of all sorts, and for various other purposes. It will not melt in the heat of our most powerful furnaces, — a property of much importance, but of the less value, as it prevents the possibility of casting it into different forms. Even this defect is nearly countervailed by the property which, like iron, it possesses, of welding; two pieces may thus be united, by laying them in contact and hammering them while they are raised to an intense heat. It does not rust or corrode when exposed to air or moisture; and if heated in the hottest furnace, it comes out bright and untarnished. Notwithstanding all these advantages, platinum is of little use to mankind, for its price is just as high as its properties are valuable: hence its limited employment in the arts. Its colour is white like silver; its specific gravity is 21·47: it has been drawn into wire so thin as $\frac{1}{30000}$th of an

inch, but only in short lengths, and not very perfect. The number of its oxides is not agreed on by chemists; there are probably four.

There is a form of this metal which possesses some extraordinary properties; it is called spongy platinum. It may be prepared by dissolving platinum in a mixture of nitric and muriatic acids by heat: to the solution must be added solution of muriate of ammonia, while it continues to precipitate any thing; the precipitate, filtered off, must be washed with water, and dried in the air. If a small quantity of this powder be heated in a candle, it will become incandescent, as if it took fire. It is, when cold, fit for use. If a jet of hydrogen, from a tube of very slender bore, be directed on it from a little distance, the metal immediately becomes red-hot, and it sets fire to the hydrogen. This may be repeated a great number of times; but the sponge at last loses its power: the smaller the quantity, the sooner its power is lost. The lower the heat, to which the powder was exposed in the candle, consistently with producing incandescence, and the shorter time the heat was applied, the longer will the spongy platinum continue to produce the phenomenon, and the more certainly it will act. The cause of this effect is not known.

The combinations of platinum with metals and other simple substances are very numerous.

Potassium.—This metal may be obtained in a variety of ways: the simplest, is to abstract oxygen from potash, by exposing a mixture of dry carbonate of potash, with half its weight of recently burned charcoal, to a strong heat in an iron bottle coated with Stourbridge clay, and having a pipe proceeding from the bottle, so contrived that it can be kept cold with ice, and the air excluded. Potassium distils over, which condenses into a solid metal. Its colour, when it is newly cut, is white, like that of silver, but it rapidly tarnishes in the air: to be preserved from change, it must be kept under naphtha; that substance not containing any oxygen. It is a conductor of electricity: its specific gravity is 0·865, water

being 1·000; it, therefore, although a metal, is lighter than water, and swims upon it. At ordinary temperatures, it may be moulded by the fingers; at 32°, it is brittle; at 150°, it melts perfectly; and rises in vapour in a heat a little below that of redness. When thrown upon water, it acts with great violence, swims upon the surface, and burns with a beautiful white and red light mixed with violet; and the water is found to be alkaline. It inflames when gently heated in the air, burns with a red light, and throws off alkaline fumes. It burns spontaneously in chlorine, with intense brilliancy.

Oxygen combines with potassium in two proportions: the protoxide is that which is formed when the metal is thrown into water, and which exists in common potash; it consists of 100 metal and 20 oxygen. The peroxide is formed when potassium is burnt in oxygen; it consists of 100 metal, and three times as much oxygen as in the last, or 60. When thrown into water, this peroxide gives off 25 per cent. of oxygen by effervescence, and is reduced to the state of protoxide.

What chemists call caustic potash, is a hydrate of the protoxide: it is generally prepared by depriving pearlash (common potash ignited) of its carbonic acid by means of hydrate of lime, both being diffused in water; the solution, being filtered, is to be evaporated, and the pure alkali dissolved away by alcohol. But pearlash always contains common sea salt; consequently, the resulting alkali will contain soda. To remove this source of error, I varied the process, a few years since, in the following manner:—Dissolve the salt sold by druggists under the name of bicarbonate of potash, in the smallest possible quantity of water at 100° temperature; decant, and expose the solution in a flat dish before the fire: in a few hours a crop of crystals will be obtained, which are to be separated from the mother liquor, and rinsed. The crystals are next to be boiled with their own weight of hydrate of lime and water for fifteen minutes: after due subsidence, the clear liquor is to be poured off. This is solution of caustic potash, which, having a powerful

affinity for carbonic acid, is to be carefully preserved from the air. — (*Dublin Phil. Journ.* i. 48.) If it be required in the solid state, it must be boiled down in a silver or bright iron vessel, and out of contact with the air. If solid potash be applied to the surface of the body, it destroys the part, and forms an eschar: it changes vegetable blues to green, except litmus; and it changes vegetable yellows to brownish red: it is soluble in water or alcohol. When nitre has been heated until totally decomposed, with a view of obtaining oxygen, it is not potash that remains, as was commonly supposed, but peroxide of potassium. If it be kept for a length of time at an obscure red heat only, it is not perfectly decomposed, but is changed into a salt called hyponitrite of potash.

Potassium combines with hydrogen, and forms a gas, which spontaneously burns when let to pass into the air: it is always formed when water is decomposed by this metal, and it burns on the surface; or when potassium is strongly heated in hydrogen. When potassium and sulphur, or phosphorus, are heated together, even in a vacuum, they combine, with the phenomenon of brilliant combustion, and form sulphuret and phosphuret of potassium; both of which burn when heated in air. When sulphur and pearlashes are heated, the result is chiefly sulphuret of potassium; the oxygen of the potash being abstracted by some of the sulphur, and carbonic acid expelled. If potassium be introduced into chlorine, a brilliant combustion takes place, and chloride of the metal is formed. It burns in sulphuretted hydrogen, at the same time combining with the sulphur; it burns also in hydrofluoric acid, forming fluoride of potassium; and in fluoboric acid, forming fluoride of potassium, boron being liberated. If heated in carbonic acid gas, it burns, takes oxygen from the charcoal, and the latter is precipitated: it absorbs cyanogen gas, becomes red-hot, and forms cyanide of potassium; it also takes oxygen from boracic acid, and leaves boron.

Sodium.—This metal may be obtained by any of the

processes which afford potassium. In many of its characters it resembles potassium: it is as white as silver, has great lustre, and is a conductor of electricity. It fuses at about 200°, and evaporates at a strong red heat: its specific gravity is 0·972. When heated strongly in oxygen or chlorine, it burns with great brilliancy. When thrown upon water, it effervesces violently, but does not inflame: it swims on the surface, gradually diminishes with great agitation, and renders the water a solution of soda. It acts upon most substances in a manner similar to potassium, but with less energy: it tarnishes in the air, but more slowly; it then absorbs oxygen. Like potassium, it is best preserved under naphtha. There are two oxides of sodium: the protoxide consists of 100 metal and 33⅓ oxygen; the peroxide, of 100 metal and 50 oxygen.

The protoxide, combined with water as a hydrate, is the caustic soda of chemists; it may be formed from the bicarbonate of soda, by a process similar to that given for caustic potash, and may be solidified in the same manner. Sodium burns in chlorine, and forms chloride of sodium, or common culinary salt. It combines with sulphur and phosphorus, occasioning similar phenomena to those presented by potassium; but the sulphuret and phosphuret of sodium are less inflammable.

Lithium. — Of this metal very little is known: it exists in several minerals, and its stony origin is indicated by its name. The minerals called *spodumene* and *petalite* afford it in small quantity. Its basis was proved by Davy to be metallic: its protoxide is the alkali called lithia. Its solution in alcohol, in burning, emits a red light: it has a very acrid taste; and, in some respects, acts as a caustic. It does not deliquesce; and it dissolves sparingly in water, whether hot or cold: a red heat melts it. It absorbs carbonic acid from the air: it reddens vegetable yellows: it is not volatilised by a white heat. The chloride of lithium is deliquescent and soluble in strong alcohol. Lithia has considerable neutralising power: it forms a sulphuret, which, when decomposed

by acids, affords the same products as sulphurets of other earths and alkalies. From this account, it appears that lithia acts as a kind of connecting substance between the earths and the two alkalies, potash and soda: at first, indeed, it was mistaken for soda. It exists in petalite in the very small ratio of 5 to 7 per cent.; and in spodumene 8. Lithia consists of 100 parts of the metal lithium, combined with 123 of oxygen.

Calcium. — One of the most useful and generally known of the earths is lime, the burning of which has been already described. By means of galvanism, Davy succeeded in separating from it a metal possessed of moderate lustre; but in such small quantity, that it was not possible to make sufficient experiments on it: to this he gave the name *calcium*. When heated in contact with oxygen, it takes fire, and forms an oxide, which is lime: but there is also a peroxide of calcium. Pure lime is tasteless, and insoluble in water: it readily absorbs water poured on it, swells, heats, bursts, and is converted into hydrate of lime, commonly called slaked lime; it has now acquired a taste; it is soluble in water, and the more so if the water be cold. The solution is called lime-water; its taste is styptic, followed by sweetness. Lime-water made in the cold, and, therefore, saturated, deposits hydrate of lime, if the water be raised to 212°. The alkaline properties of lime-water are powerful, and it renders vegetable yellows brown. If exposed to carbonic acid gas, or to the atmosphere containing it, the lime combines with the carbonic acid, becomes insoluble, the compound precipitates, and water remains: the water is expelled from hydrate of lime by a red heat. It is possible, but difficult, to procure lime in crystals, by evaporating lime-water at ordinary temperatures in an exhausted receiver. Every one knows that slaked lime, mixed with siliceous sand, and water added, constitutes *mortar*, a cement for building. The hardening of mortar has been supposed chiefly to depend on the absorption of carbonic acid, and the re-conversion

of lime into carbonate of lime, which is exceedingly hard, as appears in the instance of limestone. I believe the theory to be, that some of the siliceous matter is actually dissolved by the caustic lime into a paste; and that such particles of the silica as do not dissolve entirely, enter into combination by their surfaces, the compound surfaces holding the heterogeneous matter in a state of firm cohesion. This, at least, accounts for the stony hardness of mortar in the interior of thick old walls, where carbonic acid could scarcely have penetrated, and where it appears not to have been absorbed, at least in sufficient quantity, by the fact that it scarcely effervesces when treated with acids. Beside the use of lime in making mortar, it is of extensive utility in agriculture, for improving the quality of land.

Lime is best prepared for chemical purposes by intensely heating pure white marble, so as to expel its carbonic acid. Chlorine decomposes lime, when assisted by heat; the oxygen is expelled from the calcium, and the chlorine takes its place, but in double the volume: the new compound is *chloride of calcium*, — a remarkably deliquescent substance. Lime also combines with chlorine by a very weak affinity, as is always the case where the latter combines with a metallic oxide: chloride of lime is produced, — a salt chiefly used for bleaching. There is also an iodide of lime. Calcium combines with sulphur, phosphorus, and bromine. Lime, or protoxide of calcium, consists of 100 parts of calcium, united with 40 of oxygen. The peroxide contains calcium 100, oxygen 80.

Magnesium. — The employment of magnesia in medicine has rendered it universally known, and beyond that use it contributes very little to the wants of mankind. The source from which the chief supply of magnesia was formerly derived was the sea. If sea water, sufficiently boiled down, be mixed with pearlash, a white powder subsides, which, when washed, is a combination of this earth with carbonic acid derived from the alkali. There is a mineral called magnesian

limestone, consisting of carbonic acid, lime, and magnesia; and from this we now obtain abundant supplies. When the combination of magnesia with carbonic acid is exposed to a red heat, the carbonic acid is drawn off, and magnesia is left in a state of purity. During this ignition, the magnesia appears much hotter than the fire in which it is heated; a bright white light is emitted by the earth, apparently of the phosphoric kind. This phosphorescence attends the ignition of some other earths also. If a little magnesia, which has been thus ignited, and still remains a little warm, be placed in a saucer, and a little exceedingly strong sulphuric acid be poured round the edges of the saucer, there will be a hissing noise produced, and sparks and flashes of bright white light will be emitted from all parts of the magnesia. In the heat of burning hydrogen, urged by oxygen, this earth is fusible, but not in any lower degree.

The basis of this earth has been proved to be a metal; it has been obtained in brown scales, which, when rubbed against agate, leave a metallic stain of a leaden colour. If this metal, which is called magnesium, be strongly heated, it burns with a red light, and is converted into oxide of magnesium by combining with oxygen; this oxide is magnesia. Or, if magnesium be thrown into water, it sinks, slowly effervesces, and becomes covered with magnesia.

When magnesia is heated strongly in chlorine, the oxygen is displaced by the chlorine, and a chloride of magnesium is formed. If the vapour of potassium be passed over ignited chloride of magnesium, the metal magnesium is separated in brown scales.

Aluminum. — The earth alumina, when pure, is a fine light powder of brilliant whiteness; it does not dissolve in water, but soaks it with avidity, and retains it, forming a mass, which is so ductile and tenacious, that it can be moulded into any form. This paste, when heated, becomes exceedingly hard; and it is on account of those properties that alumina is always the

basis of every kind of pottery. When a mass of alumina is heated, it shrinks in bulk proportionately to the intensity of the heat; hence, it has been employed as a kind of thermometer, or rather pyrometer, for measuring high heats, which would destroy an ordinary thermometer. A gauge is used for determining the amount of the contraction. The contraction of alumina has been supposed to be an exception to the general law of the expansion of solids by heat; but it may be only apparently so. During the heating, water, which kept the particles at a certain distance asunder by its affinity, is expelled, and not fully without a white heat: cohesion may then take place the more strongly, so as to bring the particles nearer together; but they may not approach so closely to each other as if the antagonising force of calorific repulsion were not at the same time acting. Thus expansion may actually have been produced by the heat, although it is disguised by the greater ratio of contraction, owing to loss of matter (water), and consequent increase of cohesion, now more energetic, because not obstructed by affinity.

Alumina is tasteless and inodorous; but if breathed upon, it acquires a smell distinguished by the name *earthy*. This earth, in a state of purity, may be obtained from alum purified by recrystallisation. A solution of such alum is to be mixed with deliquesced pearlash in excess; the precipitate which appears is to be separated by the filter, well washed, dissolved in dilute muriatic acid, and again precipitated by liquid ammonia. The precipitate well washed, collected, and intensely heated, is pure alumina.

By causing potassium to act on chloride of aluminum, the basis may be procured in the metallic state; it is called aluminum. It is obtained as a grey powder, which, under the burnisher, assumes metallic lustre. When heated red-hot in air or oxygen, it burns splendidly; oxygen is absorbed; and an oxide is produced, which is alumina. It is excessively hard, and even capable of cutting glass. The metal is not acted on by cold water;

but at a boiling heat it effervesces in a slight degree. This metal, like iron, is a non-conductor of electricity when reduced to minute particles. When the metallic powder is thrown into the flame of a candle, it scintillates like iron burning in oxygen. Oxide of aluminum or alumina consists of 100 parts of aluminum, combined with 8 of oxygen.* Aluminum combines with chlorine, phosphorus, sulphur, and selenium.

Glucinum. — The metallic basis of the earth called glucinum may be separated by the same means as the basis of alumina. It is a very dark coloured powder, which requires the burnisher to produce its metallic lustre. It is called glucinum. When heated in air or oxygen, it burns brilliantly, and affords the oxide.

Glucina is a soft, tasteless, white powder, which, when wet, is somewhat plastic like alumina. It neither dissolves in water, nor melts in the fire. Like alumina, its salts have a sweetish taste; and both of these earths are, in this respect, opposed to magnesia, which, with acids, affords salts of a bitter taste. Glucina is of rare occurrence in minerals; it has not been converted to any use, and therefore need no further be described. Oxide of glucinum consists of 100 metal and 44·44 oxygen; this compound is the earth glucina. Glucinum combines with chlorine, phosphorus, sulphur, selenium, iodine, and bromine.

Barium. — By a complicated process, sir H. Davy separated a metal from this earth, which he thus describes: — It appeared of a dark gray colour, with a lustre inferior to that of cast iron. It was considerably heavier than sulphuric acid; for, though surrounded by globules of gas, it sunk rapidly in that fluid. It instantly became covered with a crust of baryta (protoxide of barium) when exposed to the air, and burnt with a deep red light when gently heated. When thrown into water, it effervesced violently, disappeared, and the water was found to be a solution of baryta.

* Thomson, First Princ. i. 318.

There are two oxides of barium: the protoxide is formed in the manner just described; and if this be heated in oxygen gas, a quantity of that gas is absorbed, and peroxide of barium is produced.

Baryta may be obtained from the very common mineral sulphate of barytes, by heating its powder, mixed with charcoal powder, to whiteness; dissolving the mass thus produced in water; adding nitric acid; filtering; evaporating until, on cooling, crystals form; and heating these crystals to redness for a length of time in a platinum crucible. What remains in the crucible is protoxide of barium or baryta. It is a gray powder. I absorbs water like quicklime, and slakes like lime, and sometimes emits light in slaking just as lime in large quantities does. A hydrate of baryta is thus produced, which dissolves in water; the solution is called baryta water; and the earth may be obtained from it in crystals by evaporating the water, or by the cooling of a saturated solution. Baryta water rapidly attracts carbonic acid from the air. All the soluble compounds of barium are poisonous in a high degree. The protoxide or baryta consists of 100 metal and 11·764 oxygen; the peroxide 100+23·529. Barium combines with chlorine, sulphur, phosphorus, and bromine.

Strontium. — The earth called strontia so much resembles baryta that they were once confounded. Sir H. Davy, by the same means as he obtained the metal of baryta, obtained also that of strontia. The metal strontium resembles barium in most of its properties; and there are two oxides of strontium which may be obtained in the same manner as the two oxides of barium. The protoxide is the earth called strontia; and it may be obtained from the mineral called sulphate of strontia, by a similar process to that for preparing baryta. Certain compounds of strontium possess the property of tinging flame of a deep rose-colour: the use of such compounds in theatres is well known for procuring red light. One hundred parts of the metal strontium combine with 18·181 of oxygen, to form protoxide or strontia; and

with 36·362, to form peroxide. This metal combines with chlorine, phosphorus, and sulphur.

Yttrium. — Most of the salts of this earth are sweetish to the taste; and two of them are of an amethyst colour. When yttria is melted with a proper quantity of borax, it forms a transparent glass; but it is opaque, if the quantity of borax be too great. By heating potassium with chloride of ittria, the metallic basis of the earth is obtained. The metal is procured in iron gray scales. If heated in oxygen or common air, it burns brilliantly; and an oxide is formed, which is the earth ittria. But the metal is not oxidated by water, even if boiling. The oxide is insoluble in water, tasteless, and white, and seems to have suffered a commencement of fusion. It has no action on vegetable colours. Caustic alkalies do not act on ittria, but it is dissolved by solution of carbonated alkalies. An intense heat is necessary for its fusion. Yttrium combines with chlorine and the combustibles.

Thorinum. — This is a newly discovered metal, which may be obtained by a process similar to that for obtaining ittrium. It is of a leaden gray colour, heavy, and under the burnisher shows metallic lustre. Water does not act on it. The oxide may be formed by heating the metal in common air; it burns brilliantly; the resulting snow-white oxide is the earth called *thorina.* Boiling caustic alkalies do not act upon this earth; muriatic acid dissolves it readily; sulphuric acid has much less action on it, and nitric scarcely any. Thorinum, when heated in vapour of sulphur, burns.

Zirconium. — The earth called zirconia is a harsh whitish powder, without taste or smell; it possesses no action on vegetable colours, and is insoluble in water. It is fusible at a lower temperature than any of the other earths: the heat of a good forge is sufficient to soften it. It is soluble in the mineral acids, and in solutions of alkaline carbonates. — (*Davy.*) The basis of it has been separated by the agency of potassium, and is supposed to be metallic; but as yet the chief distin-

guishing property of metals — a decided metallic lustre — has not been evinced by it. It is a perfectly black powder. Sir H. Davy, by means of a magnifier, saw particles which appeared metallic in some parts, and of a chocolate brown in others. The black powder burns at a heat below redness, and forms the oxide or earth zirconia.

We have now taken a brief survey of those metals which, on account of being of extensive utility to mankind, are generally known; but the catalogue is by no means exhausted. On the contrary, those described are exactly one half of the total number known. The metals which remain to be noticed are either useless in their own nature, or are so on account of the difficulty and expense of procuring them, or they are useful for a few purposes only; hence, little more than an enumeration will be required.

Nickel is a hard malleable metal, which, like iron, is attracted by the magnet, and, unless it contain arsenic, is convertible into a magnet. It has not been generally converted to use, on account of its scarcity. Dr. Fyfe, says, " Nickel exists also in *white copper* brought from China, in union with copper, iron, and zinc, which is supposed to be obtained from a native production called white copper ore. The composition of the white copper ore I have found to be copper 40·4, zinc 25·4, iron 2, and nickel 31·6."—(*Fyfe's Chemistry*, 620.)

The metals called *Cerium, Uranium, Molybdenum, Tungsten, Columbium,* otherwise called *Tantalum, Tellurium, Cadmium,* and *Vanadium,* on account of their scarcity, or from the difficulty of reducing them to the metallic state from their ores, are but imperfectly known, and have not been applied to any useful purpose. *Cobalt* is used for giving a blue colour to glass and porcelain: the tint is beautiful, and hence the metal bears a high price. *Manganese* is much in use; it is employed by

glass makers for two opposite purposes: for communicating a purple or violet colour; or for destroying all colour, and rendering the glass colourless. This difference of effect depends on the property, which the metal possesses, of combining with different portions of oxygen: there are four oxides known. In order to understand their action on glass, it must be observed, that iron often adulterates the materials of which glass is made, and a very small quantity of the protoxide of iron gives to glass a green colour, although the peroxide imparts no colour. Now, if to glass rendered green by a little protoxide of iron, we add a small quantity of tritoxide of manganese, it will give off a little of its oxygen to the iron, which thus becomes peroxide, and loses its colouring power. On the other hand, the tritoxide of manganese possesses the property of rendering glass purple, while the deutoxide possesses no such power; the manganese, by converting the iron into the state of peroxide, is itself reduced to the state of deutoxide; and this, like the peroxide of iron, does not colour glass: hence the original colour of the glass is destroyed, and no new colour is communicated, if the proportion have been rightly adjusted.

It is in the state of tritoxide, or black oxide, that manganese is commonly found in nature; and when this oxide is reduced to the metallic state, the metal speedily absorbs oxygen from the air, and returns to the state of black oxide. It is from the tritoxide that chemists for the most part obtain oxygen for experimental purposes; and the modern practice of bleaching cannot be conducted without it: hence, this oxide is extensively useful in the arts.

There is another metal used in coloured glass making, and glass and porcelain painting, called *Chromium;* it is also used in enamelling, and as a rich, strong, and durable pigment. To glass and enamel it communicates a green colour, while it furnishes to the painter his best and most lively yellow: its high price much limits its use.

Bismuth is one of the most fusible of the metals, and it communicates fusibility to other metals. A mixture of tin, lead, and bismuth, is so fusible, that it melts when thrown into boiling water: a toy of this kind is well known; it is a spoon which, when immersed in a very hot liquid, immediately melts. An alloy, composed of 3 parts of lead, 2 of tin, and 5 of bismuth, melts at 197°, and may be used for taking casts from gems, seals, &c. The composition is rendered fusible at a still lower heat by the addition of a little mercury. This last preparation is also used for silvering (as it is called) the inside of glass globes: the compound, when gently heated in the globe, melts; and by turning the globe, an equal coating may be laid on, which, when cold, hardens and adheres.

There is a substance pretty generally known, in consequence of its being much used in medicine, called *Antimony*. The substance to which the name is commonly given is an ore, from which a peculiar metal may be extracted; and it is to this metal that the name of antimony is given by chemists. It is white, and so brittle, that it may be reduced to powder: it melts when heated to redness; at a higher heat it evaporates. It has three oxides. Antimony, melted with 16 times its weight of lead, forms the alloy of which printing types are formed: and the alloy of tin and antimony, made into plates, is used for engraving or rather punching music.

The crude platinum of commerce is by no means pure: it contains no less than four other metals; these are called *palladium*, *rhodium*, *iridium*, and *osmium*. They are procurable in very small quantities: they have not been applied to any use; possess no very remarkable properties; and, therefore, need not be here further noticed.

The last metal to be enumerated, is one that, in a certain state of combination, is well known to the world, on account of its destructiveness to animal life: it is called *Arsenic*. This is a grayish white metal, which may be easily broken to powder. When moderately heated, it evaporates, and at the same time combines with oxygen,

forming a white coloured oxide, commonly called *arsenic*, but improperly, that name belonging only to the metal. This oxide is the well known poison.

Such is the very brief sketch of the metals at present known. It will be necessary to make a few general observations, which will render their resemblances and differences more manifest than when separately considered. In the first place, it is to be observed, that all the metals possess that property well understood by the expression *metallic lustre*, without which no substance can be considered a metal. They are of different colours: — some are white, as platinum, palladium, rhodium, iridium, silver, nickel, cerium, tin, mercury, molybdenum: some are bluish white, or grayish white, as lead, zinc, iron, arsenic, tellurium, manganese, uranium, cadmium, antimony, chromium, tungsten: two are yellow, namely, gold and titanium: copper is red; bismuth is reddish; and cobalt has a paler reddish tint than bismuth.

There are three metals magnetic — iron, nickel, and cobalt: chromium has been affirmed to be magnetic.

Some metals possess the property called malleability: gold and silver may be beaten out into leaves, almost inconceivably thin; copper, tin, platinum, and lead, possess the same property, but less perfectly: others are totally destitute of it, as arsenic, columbium, antimony, cobalt; and they can even be easily reduced to a fine powder: hence these are called brittle metals. Nearly allied to the property of malleability is ductility, which expresses the capability of the metal to be drawn out into fine wire. All the malleable metals possess this property: gold, silver, and iron may be drawn into wires as fine as a human hair: lead and zinc may be drawn into wires, but they cannot be made fine: the brittle metals, as might be supposed, do not draw.

Metals differ much in their cohesion or hardness: tungsten is so hard as to resist the file; while lead and tin may be scratched with the nail of one's finger.

With regard to the fusibility of metals, or their capa-

bility of being melted by heat, they differ from each other as much as in any other respect. Some are absolutely infusible in the greatest heats of our furnaces, as platinum (which, however, melts in the flame of hydrogen, urged by oxygen), rhodium, iridium, molybdenum, and, we may add, uranium: it requires the most powerful heat to melt manganese, nickel, and iron. Others melt long before they become red-hot, as tin, lead, and bismuth; while potassium, at common temperatures, is always an easily moulded soft-solid, and mercury is, at all ordinary temperatures, in a liquid state.

It is particularly to be observed, that metals differ very much in the facility with which they unite with oxygen. Some of them, by mere exposure to the atmosphere, absorb its oxygen with great rapidity; such are potassium, sodium: others more slowly, as manganese, iron, arsenic; and lead and copper still more slowly. Others do not oxidate by exposure to air, unless at a high temperature, as tin, zinc, titanium, mercury, antimony, bismuth, osmium, rhodium, and cobalt. Others, again, will not oxidate by exposure to air or heat, or by immersion in water, as gold, platinum, palladium, iridium; and we may say nearly the same of nickel: silver is with great difficulty oxidised by heat. There are some of these metals, which, when heated red-hot in the fire, burn with the greatest splendour, and at the same time unite with oxygen; of this kind are copper, zinc, cadmium, tin, and bismuth; columbium burns feebly: iron filings thrown into the flame of a candle, or exceedingly thin iron wire held in the external part of the flame, will scintillate: antimony burns at a white heat; and tellurium burns before the heat of the blow-pipe. In short, at intense heats, most of the metals may be burned. But if placed in a burning jet of hydrogen, on which a jet of oxygen is allowed to mix, they deflagrate with intense brilliancy and great facility. On the other hand, potassium burns by contact with a piece of ice, with as much intensity, as others do when heated in the oxyhydrogen flame just mentioned.

Some of the metals, when exposed to heat, not only melt, but obey the general law of other bodies — boiling and evaporating when the heat is sufficiently high. Thus, mercury, zinc, cadmium, bismuth, tellurium, and antimony, boil and evaporate at a moderate heat: it is even known that, in a Torricellian vacuum, mercury is evaporated at ordinary temperatures: silver and lead require a higher heat; tin and cerium a violent heat: gold will only evaporate in a slight degree, under the most intense heat that can be applied; and iron, nickel, manganese, uranium, and chromium, cannot be made to evaporate in the most intense heat with which we are acquainted. Arsenic evaporates without melting.

In evaporating, some of the metals afford a peculiar smell. Arsenic vapour has the odour of garlic; tellurium smells like horseradish; and osmium takes its name from the smell of its vapour. Some have a smell when rubbed, without being heated.

There are instances, even, of some metals assuming the state of vapour, and maintaining it permanently; but, to do so, they require to be combined with a gas. Thus, arsenic and tellurium unite with hydrogen gas, and form gases, called arseniuretted and telluretted hydrogen gas. Zinc, in small quantity, also dissolves in hydrogen. There are compounds of tellurium and hydrogen, and of bismuth and hydrogen, which are even capable of existing in the solid form; the former is soluble in water. Potassium dissolves in hydrogen, but the compound spontaneously decomposes after a while.

Some metals, when combined with oxygen, afford oxides, which possess the properties of acids; they are called *metallic acids*. Arsenic affords two oxides, which act in the double capacity of bases and acids. Of the three oxides of antimony, the deutoxide and peroxide are acids. The following metals afford each two oxides, the protoxide being a base, and the peroxide an acid: — tungsten, columbium, titanium, chromium, uranium, tin, vanadium, and, perhaps, gold. Two metals, molybdenum and cobalt, afford three oxides each; the per-

oxide of both being acids. Of the four oxides of manganese, the peroxide is an acid. The following metals produce two oxides each, both of which act as bases: — platinum, palladium, rhodium, gold? silver, mercury, cerium, nickel, iron. With zinc and cadmium, oxygen combines in one proportion only, and the oxide acts as a base. Lead and copper give three oxides each, all bases. Iridium is supposed to have four oxides; and osmium, five; but nothing is certainly known of them.

Some metallic oxides are alkaline in a high degree; such are those of potassium, sodium, and lithium. Nine other metals afford oxides of a less alkaline nature; they were formerly called earths; calcium, barium, strontium, magnesium, yttrium, aluminum, zirconium? thorinum, glucinum: the first four earthy oxides change vegetable yellows to brown, but the last six do not affect them.

Tellurium, by combination with hydrogen, is converted into an acid, as well as with oxygen. Several of the metals, when acidified by oxygen, combine with hydrofluoric acid, and form double acids; such as chromium, tungsten, molybdenum, columbium, and titanium.

The names of the metallic acids are arsenious and arsenic, antimonious and antimonic, tungstic, columbic, titanic, chromic, uranic, stannic, vanadic, auric? molybdic, cobaltic, manganesious and manganesic, telluric and telluretted hydrogen, fluochromic, fluotungstic, fluomolybdic, fluocolumbic, fluotitanic. The alkaline and earthy oxides are potash, soda, lithia, lime, baryta, strontia, magnesia, yttria, alumina, zirconia, thorina, and glucina.

Many of the metallic oxides, when taken into the stomach, act as poisons. Oxide of arsenic is a notorious and virulent poison; oxide of copper is less virulent than arsenic; oxide of lead is a painful poison; oxide of nickel is known to be a poison; and peroxide of mercury, unless in small quantities, is of a poisonous nature.

With regard to the alloys, it is necessary to observe,

that many of them are more useful than the metals of which they are composed; and possess properties a good deal different from their elements. The most useful of all alloys, brass, is composed of zinc and copper: it is harder, more easily melted, more close grained, better coloured, and less liable to tarnish, than copper; it is less brittle, and in every way more serviceable, than zinc. Pinchbeck is composed of the same materials as brass, but in different proportions, the zinc predominating. Of copper and tin — two very soft and flexible metals — are composed the alloy called bell-metal; which is harder than iron, very brittle, and sonorous. Of the same materials, but in different proportions, are composed mirrors; and the kind of ordnance, improperly called brass cannon. Pewter is composed of tin and lead, sometimes with the addition of zinc, copper, or bismuth. Plates for stamping music are composed of tin and antimony; and printing types are formed from the alloy of antimony, lead, and, perhaps, a little bismuth. Tin foil is an alloy of lead and tin; and plumbers' solder is composed of the same metals. Fusible metal is bismuth, lead, and tin. The amalgam of zinc and mercury is used for exciting electric machines; that of mercury and tin is the compound employed for what is called silvering looking-glasses. The alloy of gold and silver with copper, for coins, has been already noticed.

In our search after the metallic productions of nature, we by no means generally find them disseminated through the earth in their metallic state. Sometimes they do occur native. Gold is found slightly alloyed with silver or copper. Platinum is always found alloyed or mixed with iron, palladium, iridium, rhodium, and osmium. Copper, silver, mercury, antimony, bismuth, arsenic, and tellurium, occur both in the native metallic state (although never perfectly pure), and also mineralised by other bodies. Lead, zinc, tin, antimony, iron, &c. are constantly found combined, or mineralised by sulphur. Metals are often found combined with oxygen,

or with oxygen and carbonic acid. The combination of a metal with its mineralising substance is called an ore; and it is in the state of ore that metals occur when they are not found native. Ores sometimes possess metallic lustre; sometimes they appear stony, and sometimes earthy. In many instances they are crystallised into regular forms; and often they are amorphous (shapeless) masses. Ores are found in large fissures in rocks, called *veins;* and often in beds of earth. The reduction of them to the metallic state is, generally, a difficult process.

CHAP. II.

COMPOUNDS OF SOME ELEMENTS AS PRESENTED BY THE VEGETABLE KINGDOM.

IN treating of organized bodies, we have shown that, notwithstanding the variety of aspects under which vegetable substances are presented to us, and the striking difference of their properties, they are all composed of four ultimate elements. The combinations with each other, into which these enter, are, however, various; and each form of combination produces a substance of a different kind. These substances, associated with each other more or less numerously, compose the vegetable structure; and, being the more immediate objects of sense, in the investigation of any organisation, they are called their *proximate principles.* Existing ready-formed in woods, roots, leaves, flowers, fruits, and seeds, we find a considerable number of proximate principles, as acids, alkalies, sweet principles, bitter principles, oils, exudations; some

poisonous, others wholesome; some spontaneously separating, others remaining obstinately combined. To give a brief account of the chief of these, is the object of this chapter.

SECTION I.

ACIDS OF VEGETABLES.

Citric acid. — The acid of lemons exists in their juice, combined with a considerable portion of mucilage, which disguises its properties, and renders it perishable; it has, therefore, been an object to remove this, when the acid is to be preserved, or when its real properties are to be examined. The process which succeeds best, is, to present to the juice any substance which has a stronger affinity to the pure acid than the mucilage has; and which, by forming a compound that water cannot dissolve, will permit our washing it with water to remove the mucilage. The substance added is then to be withdrawn, and the acid remains pure. From the Latin word, *citrus*, a lemon tree, this acid has been called *citric* acid. The outline of the process is as follows: — Add to strained lemon juice as much powdered chalk as will saturate it. A powder subsides, from which the liquor which floats above should be decanted; and the powder washed with various affusions of warm water, until the washings come off without taste. Dilute sulphuric acid should be heated on the powder: the acid liquor should then be pressed out through linen, — and evaporated, until a pellicle appear on the surface; on cooling, crystals will form, which, if not white, are to be dissolved in water, and the liquor filtered, and again evaporated. In 100 grains of these crystals, there are $23\frac{2}{3}$ grains of water, and the remaining $76\frac{1}{3}$ are pure acid, in its most concentrated form. These $76\frac{1}{3}$ grains of pure acid are composed of 42·1 of oxygen, 31·58 of carbon, and 2·63 of hydrogen.

It is commonly estimated, that an ounce of crystallised acid, dissolved in a pint of water, affords an acid of the same degree of sourness as average lemon juice: according to Dr. Barker, of Dublin, 540 grains of the crystals are necessary. But water is capable of dissolving a much greater quantity of the crystals; at 60°, it dissolves one quarter more than its own weight; the solution will not keep for any great length of time. The crystals, if much heated, turn black, and are decomposed. Their shape is that of a rhomboidal prism. They dissolve in alcohol.

Sorbic acid. — Apples, when unripe, have an exceedingly acid taste. Beside a peculiar acid, the juice contains, like that of lemons, a considerable portion of mucilage. From the Latin word, *malum*, an apple, this acid was denominated *malic* acid, by Scheele, who discovered it in 1785. In 1815, I examined the acid juice of various fruits; and, amongst the rest, that of the *sorbus*, or *pyrus* aucuparia, which Scheele had already pronounced to contain the malic. But as this juice proved to contain an acid possessed of properties totally different from those attributed by Scheele to malic acid, I inferred that the acid of sorbus berries was one *sui generis*; and I described it in the Philosophical Transactions under the name of sorbic acid. Shortly after, the subject was undertaken by Vauquelin, whose results coincided pretty nearly with mine. Braconnot, also, undertook an examination of the acid; and he decided that it was a new one: but, in some time after, he made a new set of experiments; and he then declared that the acid described by me was no other than the malic, except that malic acid, as obtained by Scheele's process, is loaded with impurities, which are removed by mine. In this state the question still remains.

As the properties of the acid derived from sorbus berries are totally different from those which Scheele described as belonging to the malic, I think the name sorbic acid is less likely to occasion misconception. It may be prepared by pounding and expressing the berries

of the sorbus aucuparia, or service tree; and adding solution of sugar of lead until it cease to occasion a precipitate. The precipitate is then to be collected on a very large double filter of paper, and boiling water is to be allowed to run through until the matter on the filter has grown granular and hard. The water, on cooling, will afford beautiful crystals, which are to be separated by a filter, diffused in distilled water, and a stream of sulphuretted hydrogen passed through, until further additions cease to throw down a black precipitate: this black precipitate being filtered off, the clear liquor is to be boiled down to a syrupy consistence. This is sorbic acid, almost perfectly pure. By means too tedious to describe here, it may be made to crystallise. This acid is composed of oxygen, hydrogen, and carbon; but there is no use in stating quantities, as the results of analyses are discordant.

Sorbic acid is contained in a number of fruits, beside apples and sorbus berries.

Tartaric acid.—Every one knows, that when a large quantity of the juice of grapes is left to spontaneous fermentation, the result is wine. When wine has been kept some time to depurate in wooden vessels, it deposits, on the side of the vessel, a hard crust of dark coloured matter, the taste of which is sour. This matter is impure; but, when purified by various crystallisations, it becomes perfectly white and crystalline; and then it is known in commerce by the name of *cream of tartar*. The etymology of the singular name, tartar, is uncertain: it is derived from τάρταρος, as some say, because it occasions pains equal to those endured in the infernal regions; and, as others say, merely because this substance deposits itself in the inferior parts of the cask. Tartaric acid may be obtained from cream of tartar by a process analogous to that given for obtaining citric acid. It has an exceedingly acid taste: it dissolves readily in water, and is soluble in alcohol. Its crystals are of a very irregular shape. In 100 parts, by weight, there are 12 of water; the

remaining 88 parts are the pure anhydrous acid, composed of 32·39 parts of carbon, 52·97 of oxygen, and 2·64 of hydrogen.

This acid exists abundantly in other fruits, but especially in the tamarind; in the grape it exists along with citric, malic, and an acid called *vinic*, which resembles tartaric acid in many respects, but differs from it in others, and concerning the nature of which almost nothing is known: these four constitute the agreeable tartness of the juice of that fruit.

Oxalic acid. — The plant called sorrel is valued for its acidulous taste. This acidity is owing to the presence of a peculiar acid, which may be separated from the juice, and from the potash with which it is combined, by a process analagous to that described for the preparation of citric acid. It has obtained the name of *oxalic acid*, from the generic name of the plant, *oxalis acetosella.*

This acid forms readily into regular crystals, of which one half the weight is water, the other half being pure acid. It is a remarkable circumstance in its constitution, that it contains no hydrogen, and that it consists merely of carbon and oxygen, — there being twice as much oxygen as there is carbon. So that it differs from carbonic acid merely in the relative quantities of its ingredients. Oxalic acid can be prepared by an artificial process, with great ease, from sugar, and 6 times its weight of nitric acid, — the former affording the carbon necessary to its formation, and the latter the oxygen. It is only necessary to heat the nitric acid on the sugar; the sugar dissolves, and there is a violent effervescence, which must be moderated by immersion in cold water: when the mixture cools, crystals of oxalic acid form in abundance, which may be purified by a second crystallisation.

Oxalic acid is an active poison; many persons have fallen victims to its virulence, by having swallowed it in mistake for Epsom salt, which it resembles in appearance. In all probability, this would not prove to

be the only vegetable acid capable of acting as a poison. Chalk finely powdered, and diffused in water, is the proper antidote to the poison of oxalic acid.

Gallic acid. — We have now to consider an acid of a much less decided character, although possessed of striking properties, than any of the foregoing: it is obtained from gall nuts; and hence has been called *gallic acid.* The process for preparing it is very simple: introduce coarsely powdered galls into a glass retort, and heat the belly of the retort gently and gradually until crystals form on the neck. These crystals are gallic acid, which rises in vapour from the galls in consequence of the heat: the vapour, as soon as it comes in contact with the cool part of the glass, condenses, or becomes solid there; and new particles of acid continually fixing in the same way, and joining each other according to the symmetrical arrangement described in the chapter on cohesion, crystals are formed just in the same manner as if a liquid by cooling had crystallised. Whenever a solid is thus converted into vapour by heat, and the vapour by being cooled again becomes solid, whether assuming the form of crystal or not, the solid is said to have been *sublimed;* and the process itself is called *sublimation,* because it is generally performed in tall vessels,—the solid taking a *high* station in the vessel, as it could not cool nearer to the source of heat.

The claims of the gallic to be considered as an acid are not very decided. It has been stated by Berzelius, that it does not redden litmus; but others affirm that it does. Its taste is scarcely acid; it is rough and bitter; but it possesses the property of neutralising alkalies, and of expelling carbonic acid from the carbonates. Its most remarkable property is that of changing the colour of solutions containing iron to an intense blue-black colour; and it is partly owing to the co-existence of gallic acid and peroxide of iron in ink, that its black colour is attributable.

The crystals of this acid dissolve in 12 times their weight of water at 60°, or twice their weight of water at 212°. 100 grains of it consist of 56·25 carbon, 37·5 oxygen, and 6·25 hydrogen.

Other acids.—There are a number of other acids, which, being of little use, and not possessed of any remarkable properties, it will be sufficient merely to allude to.

Benzoic acid is contained in the odoriferous resin called *benzoen* or *benjamin*, and may be obtained by gentle sublimation in the same manner as gallic acid. *Moroxylic* acid is produced from the bark of the mulberry tree; *ulmic* acid from the bark of the elm, and from various other vegetable sources: *kinic acid* is procured from the bark of the cinchona tree,—the same which affords Peruvian bark. From turpentine, an exudation from various species of pine tree—are derived *silvic* and *pinic* acids. From poppy-heads is obtained *meconic acid*: from carrots and other vegetables, *pectic acid* may be separated. The roots of the krameria triandra, or rhatany, a Peruvian mountain shrub, contain *krameric acid*. Asparagus shoots afford *aspartic acid*. The seeds of the *croton tiglium* furnish *crotonic acid*. Beside the foregoing, there are three or four others not worth naming.

The acids which have been just described exist ready formed in the fruits, barks, seeds, seed-capsules, roots, &c. of plants; they are simple *educts*. But there are others having a vegetable origin, which do not exist in plants as acids, but may be formed by chemical changes produced on certain elements contained in vegetables which afford the base of the acid: these are acid *products*; some are produced by the agency of fire, others by the action of nitric acid.

When citric, sorbic, kinic, tartaric, and mucic acids are distilled at a high temperature, they undergo decomposition; and, by a new arrangement of the elements, new acids are obtained. Their names remain the same, with the word *pyro* as a prefix, derived from

πυρ, fire, indicating the manner of their production Thus, we have *pyrocitric, pyrosorbic, pyrokinic, pyrotartaric*, and *pyromucic* acids: they are all capable of assuming the crystalline form; and differ materially in their properties from the original acids previously to their being altered by fire.

There are other acids generated by similar means, but they have simple names without any prefix, because they are not known to exist in any previous acid state. Thus, amber, a substance of vegetable origin when distilled, affords an acid in crystals called *succinic* (*succinum*, amber). When castor oil is distilled, two acids are generated; they have been named *ricinic* and *elaiodic* acids.

When potash, a substance chiefly of vegetable origin, is exposed to a powerful heat along with carbon, an acid is produced, which, on account of its saffron colour, is called *croconic acid.* If pinic acid be exposed to heat, its nature is altered: it becomes a new acid, and has been called *colophonic*; but this is an unnecessary innovation on the established method of nomenclature; it should be denominated *pyropinic* acid. The acids which follow are generated by the action of nitric acid on a compound vegetable basis.

Carbazotic acid. Indic acid. Aloetic acid.—Indigo, when acted on by nitric acid, affords products which vary with the strength of the nitric acid employed. When the acid is strong, and its action on the indigo is maintained by a moderate temperature, the latter dissolves with considerable effervescence, and a solution is obtained, which, on cooling, deposits transparent yellow crystals. These, when purified by various processes, constitute what is called *carbazotic acid*,—the name being derived from the circumstance that carbon and azote enter into its composition.

This substance reddens vegetable blues, yet its taste is only bitter. It may be sublimed by a slow heat; but by a strong and sudden heat it is kindled, and is consumed with a yellow flame. It forms a variety of

crystallisable salts with alkalies and earths, the most remarkable property of which is that of exploding when heated.

When indigo is boiled with nitric acid much diluted, and water continually added to prevent concentration by the evaporation which takes place, a yellow solution is procured, which, on cooling, affords acid crystals. These, being purified by means not necessary to describe, constitute *indic acid*, or, as it has been called, indigotic acid,—a name which does not seem to be more expressive, although more cumbrous. This acid is obtained in white silky crystals, which have an acid bitter taste. When heated, it comports itself nearly in the same manner as the carbazotic. It consists of 45·454 parts of carbon, 40·404 oxygen, and 14·142 azote, in 100 parts. Carbazotic acid consists of the same elements; but the ratio is different; the carbon being but two thirds, the azote double, and the oxygen the same, of the quantities which compose indic acid. This appears by the analysis of Dr. Buff. When indic acid is acted on by strong nitric acid, it is converted into carbazotic.

Braconnot had discovered, that when nitric acid is heated on aloes, a yellow floculent precipitate appears, very little soluble in water, and, when pure, manifesting the properties of a peculiar acid, which he called *aloetic acid*. When this or its crystallised combination with potash is heated, it detonates with a purple flame; in the latter case the smell of hydrocyanic acid is perceptible. Liebeg obtained the same results, but he was misled into the belief that nitric acid enters into the composition of aloetic acid, and is combined with a peculiar bitter principle of aloes not possessing the properties of an acid.

But whatever might be the nature of aloetic acid, he found that it possesses some extraordinary properties. Silk boiled in its solution acquired a beautiful purple colour, which was not affected by soap, nor by any acid except nitric, and this changed it to yellow; but

mere washing in cold water restored its former fine purple. He found that all shades may be given by proper mordants. To wool, a particularly beautiful black is communicated by this substance, on which light has no influence. Leather takes a purple, and cotton a rose colour from it, which gives way to soap. To silk it also communicates a rose colour,—the only permanent one known.

M. Liebeg afterwards found that he, as well as Braconnot, had mistaken the nature of aloetic acid. His new researches informed him that aloetic acid is a compound, consisting of carbazotic acid, combined with a peculiar substance possessing the properties of a resin. Carbazotic acid, he found, is an excellent test for discovering potash; the carbazotate of potash requires a large quantity of water for its solution; hence, when dropped into solutions of potash, even of sulphate of potash, a precipitate is produced. Nay, it occasions a precipitate in infusion of litmus, on account of the minute quantity of potash which that substance contains.

The action of nitric acid on indigo was first observed by Haussmann; he obtained a bitter substance from it, which he did not recognise to be an acid. It was called the *bitter principle* of Haussmann, but was really impure carbazotic acid. Welter ascertained that, by digesting nitric acid on silk, a bitter principle, which he called *amer*, is also produced, and it was supposed to be identical with that obtained from indigo. Liebeg investigated this subject; he obtained from silk the same crystalline matter as from indigo; showed that both form the same compounds, and that they are, in short, the same acids. Chevreul had denied that the bitter principle is an acid; he considered it to be a combination of nitric acid with vegetable matter; but he ascertained that an acid may be procured from indigo by the action of dilute nitric acid. This is the acid to which the name of indic is here given.

Mucic acid. Camphoric acid. Suberic acid.—By

acting on *sugar of milk* with nitric acid, both undergo decomposition, and an acid in the form of a white powder is produced, which is called *saclactic* acid (saccharum lactis). If nitric acid be made to act on gum Arabic, the very same acid is formed; and hence it has also been named *mucic acid*, and considered to be a vegetable acid. If camphor be similarly treated with nitric acid, we obtain a substance in crystals, called *camphoric acid*. And if cork be acted on by nitric acid, a crystalline acid is generated, called *suberic*, from *suber*, the cork tree.

Section II.

ALKALIES OF VEGETABLES.

It has been discovered that acids are not the only class of bodies which constitute the most decidedly characterised component parts of vegetables. It is known that alkalies exist already formed in the plant as one of its constituent parts, in the same way as acids, and with far more decided properties; and it is certain that they are not *generated*, as is the case with potash and soda. Several of the substances which have been announced as alkalies, manifest alkaline properties in so undecided a manner, that they have been distinguished by the term *alkaloids*, in order to imply a relation or resemblance, rather than an identity with the alkaline nature. The properties of these substances are not of sufficient interest, at least to the chemist, to call for description in so small an elementary treatise as this: a few short notices shall suffice.

Quinina and *Cinchonia* are alkalies, which have been discovered existing in the different species of cinchona bark, in combination with kinic acid. They have a considerable resemblance to each other, but are sufficiently distinguished in certain properties. They have a bitter taste; they neutralise acids, and form crystal-

lisable compounds, some of which are used in medicine; and are supposed to concentrate in them all the medical efficacy of the cinchona barks; but it seems probable that this conclusion is founded on insufficient or exaggerated grounds. Cinchonia readily crystallises: it is insoluble in cold water, and requires 2500 times its weight of boiling water: alcohol and ether dissolve it. Quinina possesses nearly the same properties, but it does not crystallise. The alkaline properties of both are strongly marked. *Morphia* is an alkaline substance obtained from opium, in which it exists in combination with meconic acid. It has been supposed to concentrate in itself the sedative virtues of opium; while the stimulating effects of that medicine are imagined to reside in a different principle, *narcotine*, which may be obtained from opium in a separate form, and which does not manifest the properties either of an acid or alkali. On this subject Mr. Brande observes, "It must be admitted that the composition of the active principle in crude opium is yet but imperfectly understood: and it is possible that narcotine, in some peculiar state of combination, may contribute to its powerful qualities: it cannot be admitted that they are referable to morphia only, for 100 parts of opium do not yield more than 7 of that base; so that were morphia the true active essence of the poppy, it should produce (when extracted in its active saline state of sulphate or acetate) effects commensurate with the fourteen-fold concentration which the opium has undergone. Yet morphia, or rather its soluble salts, may be given in nearly the same doses as crude opium; and a grain of opium and a grain of acetate of morphia are not widely different in their operation as sedatives." If these facts have been observed in a sufficient number of cases, they seem to negative the statements which have been made with regard to the relation of acetate of morphia and morphia to opium, in point of strength. The former is affirmed by Orfila to be one of the most powerful narcotic poisons of all the salts of that alkali: and Ma-

jendie says, that a quarter of a grain is a full anodyne. Sertuerner found that one grain of morphia produced stupor, and that an additional half grain produced alarming symptoms. Perhaps the discordance of the different statements may be referable to the different circumstances under which the experiments were made: for solid morphia is by far less active than morphia in solution. Much is yet to be known, before the nature of morphia can be said to be understood. It is, however, a decided alkali: it is obtained as a white crystalline powder, very difficultly soluble; and to this circumstance may its inertness be attributed, just in the same way as sulphate of barytes is inert owing to the same cause. The experiment seems, however, a very unsafe one; as acids in the stomach may easily develop its powers by promoting its solution.

Strychnia is one of the most powerful bitters and poisons of all the substances in nature, and possesses the remarkable property of inducing symptoms of the disease called locked jaw. It may be said to be insoluble in water. It has of late been much used in medicine, in paralytic affections, applied in minute quantities on a blistered surface, or even given internally.

Brucia is also a violent poison, capable of inducing locked jaw and tetanus. Its intensity as a poison, to that of strychnia, is as 1 to 12. It requires 500 parts of water for its solution: it dissolves in alcohol, but not in ether. It has been extracted from the bark of a tree common in Abyssinia, called *woginoos*, or *brucea antidysenterica*. It has also been called false angustura, and was sold for real angustura, — a fraud or mistake which at the time created dreadful consequences. It is singular that Mr. Bruce, the celebrated traveller, whose name the bark bears, being attacked, while in Abyssinia, with the dysentery which ravages that country, was actually cured by taking a heaped tea-spoonful of the powdered bark of the root twice a-day, — a circumstance which induced him to bring the

seeds of so valuable a plant to England, where it has grown. The effects of this dose do not seem to correspond with the known character of the alkali which has been extracted from it. Perhaps brucea, in small doses, might have beneficial effects in the dysentery of this climate.

Digitalia is said to be an alkali procurable from the leaves of the foxglove, or *digitalis purpurea*. The only substance which I could find in foxglove leaves, that seemed likely to be the active principle, was a substance possessed of the most intense bitterness; but I did not observe that it was alkaline. I suppose that this bitter substance is the narcotic principle merely, from the analogy of other violent narcotics, which are almost always bitter.

Hyoscyama, *Atropia*, *Veratria*, *Emetina*, &c. are derived from henbane leaves, deadly nightshade leaves, white hellebore root, and hippo root, &c.: they need not be described.

Section III.

OTHER PROXIMATE PRINCIPLES OF VEGETABLES.

Having now briefly described the acids and chief alkalies which are found in vegetables, we proceed to some other proximate principles.

If we take any recent vegetable, and boil it for a length of time in water, then pour off the water, add new water, and boil again, and so on, five or six times, the plant will be much changed in its nature. It loses its taste; its medical qualities, if it possessed any; perhaps its colour; and most generally nothing remains but an inert fibre, possessing no other properties than those of wood, and resembling common wood in all its physical qualities. It is, in fact, *woody fibre*, and constitutes the solid basis of all vegetable structures. It is called *lignin*, from *lignum*, wood; and it consti-

tutes from 96 to 98 per cent. of the weight of the different kinds of wood. — (*Thenard.*)

When lignin is subjected to distillation in an iron tube or retort, the same changes occur (p. 125.) as those which take place in the distillation of wood; the same gaseous compounds of oxygen and carbon, and hydrogen and carbon, the same peculiar kind of acetic acid, are evolved, and charcoal remains. Hence, lignin is composed of oxygen, hydrogen, and charcoal, just like wood; there being, in 100 grains, 52 of carbon, and 48 of oxygen and hydrogen, in the ratio which forms water.—(*Gay-Lussac* and *Thenard.*) There seems also to be some azote present, although its quantity has not been estimated.

The most remarkable of the properties of lignin, or rather of mere wood, have been discovered only of late; and although very striking, they seem not to have been followed up with the perseverance which their importance demands. If sawdust, obtained from the wood called hornbeam, which is an exceedingly hard sort of timber, be well mixed up with a sufficiency of strong sulphuric acid; and when the mixture has grown clear, if chalk be added, and the liquid strained, and boiled down to dryness; the substance remaining in the vessel very closely resembles gum Arabic. It has no taste; it is transparent and yellow; it breaks shining like gum; will unite fragments just as solution of gum does; and, like it, forms a varnish when its solution is laid on evenly.

But a still more singular fact is, that if this peculiar gum from wood be once more mixed with sulphuric acid and heated, the gum is converted into a sugar, which, in many respects, resembles common sugar: it is crystallisable.

M. Braconnot, who ascertained these remarkable facts, further discovered that a piece of hemp cloth can be dissolved in sulphuric acid, and that the same products, gum and sugar, may be obtained: for the chief constituent of hemp is lignin. He also found that the

sugar thus produced is mixed with a peculiar compound of sulphuric acid and vegetable matter, which is easily separable from the sugar, and which possesses acid properties different from those of all other acids. He gave it the name of *vegeto-sulphuric acid.* It differs from sulphuric acid in not producing any precipitation when poured into solutions of lead or baryta. When the salts formed by it are decomposed by heat, the vegetable matter is resolved into charcoal, part of which decomposes a portion of the sulphuric acid, and evolves sulphurous acid; the remaining part of the sulphuric acid combines with the base of the original salt, forming a sulphate; and this is found mixed with the residual charcoal.

These changes appear extraordinary to those who are as yet unacquainted with the composition of the bodies concerned. But when we come to reflect that wood, hemp, gum, sugar, and various other vegetable substances, are composed of the same elements, combined in different ways and different proportions, the conversion of one into another by artificial processes becomes less amazing. We are then less surprised that the carbon, oxygen, and hydrogen, which this moment constitutes wood, should the next moment be the carbon, oxygen, and hydrogen, that constitutes gum or sugar. Lignin consists of the same elements in all kinds of wood; its difference of hardness is attributable to the state of cohesion.

With lignin are associated various other bodies in different woods and plants. *Resins* exist abundantly in them, and in great variety. In the different species of pine-tree we discover that peculiar liquid resin called *turpentine.* We find it exuding spontaneously, and in the greatest purity, from wounds made through the bark, or from the sections of lopped branches; and the cones of the larch smell strongly of it. Turpentine is sometimes transparent, sometimes opaque; but it always becomes transparent and hard by age. When submitted to distillation, a thin, colourless, highly odorous liquid comes over, consisting of hydrogen and carbon, and called essential oil, or spirit of turpen-

tine. What remains in the body of the still is common resin or *rozin*, and is called white resin, if the water (which is always put into the still along with the turpentine) was not all boiled away; or black resin, if it was. Different trees and shrubs afford different resins by spontaneous exudation; some of them being odoriferous, as myrrh, olibanum, &c.

Resins are nearly transparent, and always coloured: by age their colour becomes much deeper; they have a pungent taste, and contain a strong smelling oil. Amongst their most characteristic properties are, their insolubility in water; their ready solubility in alcohol, with which they generally form a varnish; and their re-appearance in the state of a fine white powder floating in the liquid, when water is added to their alcoholic solution. If a resin be heated, it generally melts; but on cooling, it hardens again: if much heated, it burns with a dense flame and much smoke. When a resin is exposed to heat in a distilling apparatus, the odoriferous oil distils over, and leaves the resin behind; and so far altered, that it is now harder, darker coloured, and, comparatively, destitute of smell. In this odoriferous oil is supposed to reside almost the whole of the medical virtues which this class of bodies are sometimes valued for possessing; and, being considered the chief ingredient or the *essence* of the thing, it has obtained the name of *essential oil*. From the circumstance of its speedily evaporating, or flying off, when exposed to the air, it is also called *volatile oil*.

Essential oils vary much in their physical qualities: their smell and taste, both pungent, differ in each case: their colour is generally very light when newly distilled, but by age they become brown: they are mostly pale yellow, but some are green, and others blue. When shaken with water, they appear to mix for a moment; but in a few minutes almost the whole of the oil either swims or subsides to the bottom, according to its specific gravity. But the water acquires much of the pungent and peculiar taste of the oil; a proof that some

of the oil has remained in solution. Time causes a greater quantity to dissolve.

Essential oils are obtained from resins, from the bark of the wood, from the wood itself, or from the leaves, flowers, or rind of the fruit. The seeds of plants almost always contain an oil; but its nature is generally different from that of an essential oil. When exposed to the air, it does not evaporate, but leaves a greasy stain, and remains fixed; and from this circumstance it has been called *fixed oil*, in opposition to volatile oil. Some seeds, however, contain a volatile oil of great fragrance.

Fixed oils have always a greater consistence than volatile oils; their taste is mild and bland; they do not dissolve in any quantity of water; and they are much less inflammable, generally requiring to be heated to their boiling point, which is in all cases high, before they catch flame; while volatile oils catch flame at much lower temperatures. Volatile oils are inflamed by the affusion of nitric acid; but fixed oils require a little sulphuric acid to be mixed with the nitric. The former dissolve readily in alcohol; but of the latter a few only dissolve.

There are two substances found in plants which seem to have some analogy to fixed and volatile oils; these are *wax* and *camphor*. When wax is melted, it possesses many of the properties of a fixed oil: it may be considered both as a vegetable and an animal substance. It is known to be wax that constitutes the varnish on the leaves of trees, which proves it to be a vegetable substance. Bees, when confined in a room, and fed with sugar, will produce a comb composed of wax; the sugar has, therefore, been converted into wax by the animal process which it undergoes in the bee. The myrica cerifera shrub produces what is called *vegetable wax*. A good shrub affords seven pounds of berries, and these, boiled in water, give out one pound of greenish wax.

Camphor seems to possess the properties of a concrete volatile oil to a certain extent, although it must be ad-

mitted to be matter of quite a distinct nature from all other bodies. It is volatile; has a pungent taste; scarcely dissolves in water; is soluble with facility in alcohol, from which it may be again separated by mixing water with the solution. It also dissolves readily in oils, whether fixed or volatile. It is obtained by sublimation from the laurus camphora. But a small quantity naturally exudes from the trees in grains, and falls to the ground. There is a very precious sort in Ceylon, which is never imported into Europe: it comes from the roots of the cinnamon trees.

A class of bodies should also be mentioned, in almost every respect resembling resins, except that one of affording a substance when submitted to distillation, which resins do not. When heat is applied to these substances, a volatile oil, as usual, makes its appearance, and trickles down the sides of the vessel. But a little nearer to the source of heat, we find a vast assemblage of brilliant, white, downy crystals, of great beauty: they have a fragrant odour, and an aromatic taste: they dissolve in 24 times their weight of boiling water; and the solution reddens litmus, and neutralises alkalies. Hence these crystals are an acid; and as they are generally obtained from a resin called benzoen, the crystals are called *benzoic acid.*

Any resin, whether soft or hard, which, when heated in a distillatory apparatus, affords an essential oil, and benzoic acid, is designated by a peculiar name: it is not then called a resin, but a *balsam* There are, however, substances of a resinous nature, which are commonly called balsams, but which, as they do not afford benzoic acid when distilled, are improperly so called: thus, the substance called *copaiba balsam* is merely a resin or turpentine, it affording no benzoic acid.

There is another variety of resins, called gum resins; they are so named, because they are composed partly of a resin and partly of a gum.

The chief properties of pure gum—gum Arabic, for instance—are, transparency, tastelessness, perfect solu-

bility in water, viscidity of the solution, capability of cementing fragments, and of affording a varnish, its total insolubility in spirit of wine.

The properties of *gum resins* are mostly intermediate between those of gum and resin: if they be digested in water, the gum dissolves, and leaves the resin insulated; if they be digested in spirit of wine, the resin dissolves, and leaves the gum insulated; and if they be digested in a mixture of spirit of wine and water, the effect of the two solvents is exerted, or, rather, a liquor of new powers is thus produced, and a great part of both the gum and the resin dissolves. Such a mixture is, therefore, made use of in pharmacy for extracting the virtues of gum resins, when they are to be used as medicines.

Something allied to the nature of resins, although essentially different in most of its properties, is the substance called *Caoutchouc*, otherwise named *Indian rubber*, or *gum elastic*. It is the exuded juice of a peculiar tree, which gradually pours out when the bark is stripped. It is a milky liquor, that hardens when exposed to air, and becomes so elastic as to permit its being drawn out into threads. A tolerably strong heat melts it into a liquid, which forms an excellent transparent varnish, applicable to iron utensils, in order to prevent their rusting. Caoutchouc dissolves in essential oils, particularly that of turpentine, in coal naphtha, and in ether; but it does not dissolve in alcohol or water. Its solutions are used as elastic and air-close varnishes. It is, according to Faraday, composed entirely of carbon and hydrogen.

A substance, in external appearance somewhat resembling newly solidified caoutchouc, may be obtained from wheaten flour. A quantity of flour is made into dough with water: the dough is then well worked in the hand under the surface of a large quantity of water, until it no longer whitens the water. What remains in the hand is the substance in question: it is of a gray colour, somewhat like new caoutchouc; but it does not grow black by age like the latter. It is

exceedingly elastic, and may be drawn out to a thin film; yet it will shrink with elastic force to its former dimensions, when allowed to do so. It may be dried in a gentle heat; and then it becomes semitransparent, hard, and horny, and very much resembles glue. In its moist state it undergoes a putrefactive process, after which, and not before, it dissolves, although not entirely, in strong spirit of wine; and the solution is applicable to the uses of a varnish. From the glutinous nature of this substance, it has been called *gluten*.

Gluten thus obtained ought not to be considered a proximate principle of vegetables, if it be true, as has been affirmed, that it consists of two other proximate principles, which may be separated by kneading gluten in alcohol, until the spirit takes nothing further from the gluten. By evaporation of the spirit, a semitransparent, yellow, brittle substance is obtained, of a sweetish taste; it is combustible, and burns with a voluminous flame. This substance has obtained a name derived from γλια, gluten; it is called *gliadin*. That part of the gluten which remained in the hand after being kneaded in the spirit of wine, is now hard, tough, and dark coloured. It is called by its discoverer *zimoma*, from ζυμη, a ferment; but in English it should be called *zimomin*.

Zimomin possesses one remarkable property, which may be turned to some account. When mixed with that gum resin used in medicine, called *guaiacum*, the mixture will, on exposure to the air during a few minutes, become greenish blue. Guaiacum powder mixed with wheat flour produces a similar change, more intense as the quantity of gluten in the flour is greater; and in this way guaiacum may be made a measure or test of the quantity of this indispensable ingredient. That flour which has been damaged, and in which the gluten is deficient, will afford a colour of little intensity. Perhaps the same property may be found of use to maltsters and brewers.

The facts relating to zimomin and gliadin were

originally brought forward by Dr. Taddei, an Italian chemist. They have been called in question by Berzelius, who admits that the gluten obtained by kneading wheat flour under water, is certainly a compound of two proximate principles; but that one is the gluten of former chemists, and the other a substance which has been found in various vegetables, called *vegetable albumen*, to distinguish it from animal albumen, hereafter to be described.

Vegetable albumen constitutes no less than one quarter of the whole weight of sweet almonds; and, according to Boullay, is the basis of all emulsive grains in place of starch; at least, to the test of iodine, there is no discoverable quantity of starch associated with vegetable albumen in sweet almonds. And Thibierge also showed that, in mustard seed, the basis is albumen, not starch. In Boullay's opinion, it is the great quantity of this substance present in emulsive grains, which renders them indigestible. According to the analysis of Vogel, vegetable albumen exists in bitter almonds, but combined with oil; constituting a vegetable cheese, amounting to 30 per cent. of the weight of the almonds. This albumen, like that of animals, is soluble in cold water, but is coagulated by boiling, and rendered insoluble: both kinds resemble each other also in the common quality of counteracting the poison of corrosive sublimate. — (*Taddei.*) It has been shown by Einhoff and Vogel, that both starch and vegetable albumen exist in the nutritive grains; the latter only in a very small quantity.

The water in which flour has been kneaded, with a view of separating the gluten, is rendered white with a quantity of floating powder. If this water be allowed to settle, a fine white sediment will subside which, when collected and dried, constitutes starch.

Starch dissolves in neither cold water nor in spirit of wine; but it dissolves in hot water with facility, and forms a kind of jelly of well known use.

One of the most remarkable properties of starch, or, as

it is otherwise called, *fecula*, is that of being convertible into sugar by the action of diluted sulphuric acid. When these two ingredients are boiled together for a great length of time, and some chalk added, the liquor, when strained and evaporated, will furnish crystalline spherules of sugar, the quantity of which is about one tenth greater than that of the starch. This sugar is convertible into ardent spirit, like the common kind. Even a mixture of starch and water, exposed to each other's action for two years, is found to contain sugar.

A natural process, similar to this in its results, takes place in the malting of barley: the starch of the grain is converted into sugar, as will be hereafter shown. Starch also appears convertible into a kind of gum, by slightly scorching it: it then dissolves in cold water: it is called in the arts, British gum.

Starch is afforded, not only from the different kinds of grain, but from potatoes, and many other kinds of vegetable substances. Potato starch is often substituted for another kind of starch, much in demand as an article of food, called *arrow root*, which is obtained from the roots of a West India plant. The nutritious substances called *sago* and *tapioca*, or *casava*, are merely varieties of starch extracted from different sources. The presence of starch in any thing may be always detected by the azure blue which solution of iodine added to it produces.

From the facts stated, it appears that the nutritious grains consist of gluten, vegetable albumen, and starch; or, according to Taddei, of the two last, with zimomin and gliadin. The starch of potatoes, as well as that from grain, is convertible, by means of sulphuric acid, into sugar.

Sugar obtained in this way is by no means comparable, in point of sweetness, and purity of flavour, with the kind which ordinarily obtains that name. The sugar of the sugar-cane need not be described. There are two kinds, soft and hard; the latter being the purer, although it may be still further refined. Either kind, if dissolved in a small quantity of water, and exposed to cold, will form into regular crystals:

these are called *candied sugar*: the colour of the crystals will be the same as that of the sugar employed. When the juice of the sugar-cane is sufficiently purified and evaporated, the sugar crystallises in small grains; and the blackish brown syrup which remains, is called *molasses* or *treacle*.

The average produce of raw sugar, from 100 gallons of cane juice, is 108 pounds; and the average quantity of refined sugar procurable from 1 cwt. of raw sugar is 61 pounds, along with 18 pounds of bastards, and 28 pounds of molasses, — five pounds being waste in the process.* The analysis of sugar will be hereafter given under the consideration of fermentation.

Sugar is derived from many sources: it is commonly obtained from the sugar maple tree, from beet root, and grapes. The first method is resorted to in America; the two last in France. Grape sugar is easily crystallisable — not into regular crystals, but into grains which form groups of a tubercular shape, resembling those observable in cauliflowers. Nothing is easier than its formation: grape juice is to be saturated with chalk, clarified with white of eggs or blood, and evaporated. After some days, it assumes the form of a crystalline mass. — (*Thenard, Traité*, iii. 201.)

The substance to which the name *extractive matter* has been applied, is no longer admitted as a peculiar proximate principle. It is quite clear, that if a vegetable be boiled in water, removed, and the water boiled down to a soft-solid consistence, the result must be a mixture of all the soluble substances which the vegetable contained. There is, therefore, no such thing as extractive matter known.

But there is a substance obtainable from certain kinds of vegetable matter, by the above-mentioned process of extraction, which possesses remarkably distinctive properties. It may be procured from oak bark, nut galls, and some vegetable substances which have an astringent taste, by boiling in water, and evaporating the decoction

* Porter on the Sugar Cane. London, 1830, pp. 73. 272.

to dryness; a mass will result, containing several ingredients, — amongst which is one, in particular, of great importance in the arts; it is called *tannin*; and it is so named because it is the material employed in tanning leather. To obtain tannin in a state of purity, a complicated process is required: in gall-nuts it is associated with gallic acid. Dr. Turner recommends Mr. Warrington's modification. A concentrated hot infusion of nut-galls is agitated with white of egg, and the mixture filtered. Sulphuric acid is added to the liquor when cold, as long as a precipitate falls. The precipitate, consisting of sulphuric acid and tannin, is washed with dilute sulphuric acid, pressed in folds of blotting paper to dry it, dissolved in water, and macerated with fine powder of carbonate of lead. By filtration, a solution of tannin is obtained, which, by evaporation *in vacuo*, affords a hard mass. This, digested in ether, filtered, and the filtered solution evaporated, leaves pure tannin.

This substance is inodorous and colourless. It has a rough, astringent, bitter taste. When its solution is dropped into isinglass dissolved in water, a precipitate instantly appears, which is perfectly insoluble in water. The same happens with solution of glue, or *gelatine*, hereafter to be described. The gelatine, to be acted on, need not be in solution: it will succeed also in the solid state, if it can be penetrated by the tannin. The skins of animals are composed almost entirely of gelatine. The process of tanning hides depends upon these relative properties. The skin is immersed in an infusion of oak bark, the tannin of which, combining with the gelatine of the skin, renders the latter hard, dense, tough, and insoluble, and counteracts its tendency to putrefaction. The skin is now converted into leather, or it is tanned. There are many substances which contain tannin, and may be economically applied to this use. The tannin procured from these sources has different properties, and different names. The substances called kino and catechu, contain a large quantity of tannin,

but the properties differ in some respects. An *artificial tannin* has been formed by dissolving charcoal in dilute nitric acid, which possesses the property of forming an insoluble compound with gelatine: and is, therefore, capable of tanning. In some respects, this kind of tannin differs from the natural.

All kinds of tannin may be obtained in the solid state, by evaporating the water at a low temperature.

CHAP. III.

COMPOUNDS OF SOME ELEMENTS AS PRESENTED BY THE ANIMAL KINGDOM.

In a former part of this volume, it has been shown that vegetables are composed of three principal ingredients—oxygen, hydrogen, and carbon; united, in some cases, with small portions of azote. Animal matter is distinguished by the constant presence of a much larger quantity of azote: there is also generally a greater proportion of carbon than is found in vegetables, and the carbon of animals is much less easily combustible.

Beside these elements, we occasionally find others, which are common to the three kingdoms of nature. These will best appear by stating the composition of the chief parts of the animal body.

The solid part of *bone* consists of phosphate and carbonate of lime; but, beside these compounds, there are two other ingredients, which exist in recent bone in considerable quantity, and impart firmness to a structure which, without them, would be brittle, and even friable. These substances are *cartilage* and *gelatine*. Fat is also present, which adds somewhat to the toughness.

Cartilage may be obtained from bone, by immersing it for a length of time in dilute muriatic acid; the earthy and other salts, and the gelatine, are all dissolved

by the acid, and a substance remains, still preserving in a great degree the form of the bone. When the adhering acid is well washed away, the substance which remains is cartilage: but if the muriatic acid had been very much diluted, it will dissolve only the salts, and the residuum will consist of both gelatine and cartilage.

When bones are boiled for a length of time in water, the gelatine dissolves, and the water, on cooling, will *gelatinise*; that is, will become a tremulous jelly. The fat is found floating on the surface. The bone now consists of the same ingredients as before, without the gelatine. If the original bones were derived from a young animal, had been broken to powder, and boiled for a great length of time in water, both the gelatine and cartilage would dissolve, and nothing would remain in the bone but the insoluble earthy salts. The difficulty of dissolving away the cartilage increases with the age of the animal, and the quantity of the cartilage diminishes in proportion as the animal is old. The bones of very young animals are almost entirely cartilage; and the cartilage of old animals is often partially or totally converted into bone. The skeleton of the *ossified man* in the anatomical museum of Trinity College, Dublin, affords extraordinary instances of the conversion of cartilage into bone through disease, even in comparatively early age. The cartilage of some parts is more easily soluble in boiling water than others; and sometimes a portion will occur, which no boiling in water will dissolve. Bones boiled under the pressure of a Papin's digester more easily give out their gelatine and cartilage, but the taste of the solution is empyreumatic, if not ammoniacal: a loosely covered vessel is best.

When strong solution of gelatine cools, it becomes somewhat stiff and tremulous. If the solution be boiled down considerably, the residuum, on cooling, becomes a hard, brittle, transparent substance. These changes are well understood in the culinary art. When bones or meat are boiled, the gelatine which they contain dis-

solves in the water. This water, now consisting chiefly of dissolved gelatine, constitutes broth or soup: and, if it be allowed to cool, it will form *animal jelly*, which may be flavoured either with sweet or saline and aromatic condiments. If the mere jelly be boiled down so that the water shall be almost entirely evaporated, the gelatine and cartilage which remain will, on cooling, solidify, and form the hard transparent substance called *portable soup*, when it is obtained from esculent materials; or *glue*, when it is prepared from indiscriminate sources, such as skins, horns, hoofs, bones, and the fœtus of the cow obtained from slaughter-houses.

Thus, bone is composed of a number of materials: according to Berzelius, it contains gelatine and cartilage 32·17, blood vessels 1·13, fluoride of calcium 2, phosphate of lime 51·04, carbonate of lime 11·30, phosphate of magnesia 1·16, and soda, with muriate of soda, and water, 1·20. Bone ashes contain also sulphate of lime, in some way generated during burning. When bones are heated red-hot in a close vessel, the whole of the animal matter is dissipated except the *animal charcoal*; and this gives the residuum an intensely black colour. Bones thus burnt to blackness, and finely powdered, are known in commerce under the name of *ivory black*. But when bones are burnt in an open fire, even the carbon is burnt off, and the residuum is perfectly white: it is then called bone ashes, and is of extensive utility in various arts. During the distillation of bones, carbonate of ammonia is generated in large quantity; and the larger, if much common air finds its way into the vessels. Beside this, an empyreumatic oil of insupportable fetor distils over.

The presence of gelatine is not confined to the bones; it is also found in those fleshy collections of fibres called *muscles*, in which resides the strength of the body, and which direct and originate the motions of the bones. Not only is this substance contained in muscle, but an additional quantity may be formed by boiling muscle for a great length of time in water. Gelatine is, there-

fore, one of the ingredients of muscle; but there is another of far greater importance, and present in much greater quantity. When muscle is well washed in repeated quantities of water, from being red it changes to white; mere inspection will then evince that it is composed of a vast number of fibres, and from this circumstance it is called *fibrin*; the gelatine has been washed away, and may be found in the washings. It is not here necessary to advert to the fat, the cellular substance, the blood vessels, and nerves, which are disseminated throughout the substance of the fibrin constituting muscles.

Fibrin, while recent, is elastic: but, when perfectly dry, it is somewhat horny and transparent. In neither state has it taste or smell. When dilute nitric acid is made to act on recent muscle, azote in a state of purity is given out abundantly. Fibrin or muscle is converted into a jelly by the action of strong acetic acid and heat; some azote is given off when the jelly is dissolved in water; and, by strong sulphuric acid, the fibre is changed into a substance called *leucine* (λευκος, white), without any production of sulphurous acid. The process is, to heat a piece of muscle, well washed and wiped, with about its own weight of sulphuric acid. Dilute the solution thus obtained, when cold, with water; boil it for nine hours, constantly supplying the waste of water. Saturate with chalk; filter; and evaporate to dryness. The residuum should be boiled in alcohol. On cooling, the alcoholic liquor will deposit leucine. It is a white powder, which has the taste of boiled meat, and, when heated, emits the smell of roasted meat. This substance acts as a compound acidifiable base. Nitric acid converts it into a crystallisable acid, called *nitroleucic*.

Beside fibrin and gelatine, muscle contains *animal albumen*, presently to be described. But a much more important substance is also present: it is a kind of extractive matter, which is supposed to be the chief ingredient that communicates to soups and broths their peculiar taste and smell: and the greater the quantity

present, the better is the soup. It was discovered by Thouvenel, and was named by Thenard *osmazome* (οσμη, smell, ζωμος, broth). It may be formed by macerating and pressing slices of raw muscle in successive quantities of cold water; evaporating the mixed waters by heat; skimming off the albumen as it coagulates; allowing the evaporation to continue gently until the consistence of a syrup be attained. This is composed of a little gelatine, the salts present in the muscle, and osmazome. By dissolving the syrupy matter in alcohol, the osmazome only dissolves, and it may be recovered by evaporating the alcohol. It is soluble in water; does not gelatinise it; and the solution is not coagulated by heat. Its concentrated solution has an acidulous taste; and this is very perceptible in strong, well made soup.

When muscle is exposed for a great length of time to a constant stream of running water, it becomes totally changed in its appearance. It now possesses some of the properties of spermaceti, and is fusible and combustible: it is called *adipocere*.* Nearly the same substance may be formed by digesting muscle in dilute nitric acid; or it is produced when dead bodies, in great numbers, are left in a heap, and covered up with earth in such a manner as to exclude the air. Some suppose that adipocere is merely the fat a little changed, which is found disseminated throughout all muscle, the fibre being decayed away. Others conceive that it is a real conversion of the muscular fibre into fat. I have observed that alum leather, cut small, and digested in dilute nitric acid, is at length converted into a fat, perhaps of this kind.

Nearly allied to gelatine in their nature are the *tendons*, which muscles terminate in, and which conjoin muscles with bones; the *ligaments*, which connect the joints of bones; the *membranes*, which form cavities or line

* The poet Southey subjoins the following note to his Thalaba, ii. 155. — "The common people of England have long been acquainted with this change which muscular fibre undergoes. Before the circumstance was known to philosophers, I have heard them express a dislike and loathing to spermaceti, because it was dead men's fat.' "

them; and the *cutis vera*, which covers the body. All these, when boiled in water, afford gelatine in abundance, but no fibrin; they are almost entirely soluble in water by long boiling: tendons dissolve completely.

There is an abundant animal proximate principle found in many parts of the animal structure, called *albumen*: it occurs nearly in a state of purity, in what is called the *white* of the egg. It is soluble in cold water, but coagulates when the solution is boiled. Egg albumen, by continued moderate heat, may be solidified into yellowish, brilliant flakes, which are still soluble in water. I found that 12 average hen eggs afford $1\frac{3}{4}$ ounce of perfectly dry albumen. White of eggs instantly decomposes solution of corrosive sublimate; a precipate appears, consisting of calomel and albumen, which, of course, is not poisonous. Hence, white of eggs is used as an antidote to the poison of corrosive sublimate.

Of this albumen in the coagulated state, along with gelatine, are composed *nails*, *horns*, and *hoofs*.

The *brain* has been examined by Vauquelin and John; and, in this difficult analysis, a surprising coincidence between their results may be observed. It is a curious fact, that in the brain of man no less than 80 per cent. of the weight is water. According to the analysis of Vauquelin, 100 parts of human brain consist of 80 parts of water; 4·53 of white fat; 0·7 of red fat; 1·12 of osmazome; 7 of albumen; 1·5 of phosphorus, united with the fats; 5·15 of sulphur, biphosphate of potash, phosphates of lime and magnesia, and other salts. Of such materials is the thinking organ of man composed. The spinal marrow and nerves are similarly constituted. The ratio of water in the brain of the calf is also 80 per cent.

Of the fluids of the animal body, one only need be noticed, — *the blood*: this fluid is intimately connected with functions the most important to life of any other, — respiration and the generation of animal heat.

Of the appearance of blood when first drawn, little need be said: it is well known to be a somewhat viscid

red liquor, exhaling a vapour of a peculiar odour. When it is left at rest a few hours, its appearance is very much altered: it has separated into two parts: one quite liquid, of a greenish whey-like appearance, and hence called *serum:* the other is an elastic firm jelly, of a crimson red colour; this is called the *crassamentum,* because it is of a thick consistence, and resembles a deposit.

This mass is generally a little cupped on its surface, and rounded every where else. If drawn in a state of disease, it is sometimes much more cupped; and the fibrin, separating from the colouring matter, appears on the surface of crassamentum of a buff colour, hence called the *buffy coat:* these are frequently symptoms of the existence of inflammation; and the cause of them has given rise to much unsatisfactory discussion. The crassamentum is less abundant in proportion as the animal is exhausted by disease, or has lived upon scanty or deteriorated food. In fœtal blood, the crassamentum contains less fibrin than in more advanced life.

If some crassamentum of blood be washed with repeated portions of cold water, it totally parts with its red colour to the water, becomes white, and a fibrous matter remains, which, when subjected to analysis, proves to be the same as the substance already described under the name of fibrin, as obtainable from muscle.

If the water used for washing away the red portion of the blood be evaporated to dryness, at a heat much under boiling, a very dark, almost blackish red, substance will remain. This is the *colouring matter* of the blood: obtained in the foregoing manner, it is soluble in water, and in several acids and alkalies. Sulphuric acid, diluted with 8 or 10 parts of water, and heated on the colouring matter, dissolves it, and forms a beautiful lilac solution. Nitric acid destroys or injures its colour. Alkalies form deep red solutions with it. In cold-blooded animals it is easy, with the aid of a microscope, to perceive abundant red globules, floating in the serum: and if human blood be agitated

while cooling, and the fibrin which separates be removed, the liquid will, on standing some time, deposit the colouring matter, which the microscope will discover to consist of minute globules. This colouring matter is now believed to consist of animal matter. The French chemists asserted, that it is composed of the subphosphate of iron dissolved in serum: but this statement has been proved to be incorrect. The globules, combined with peroxide of mercury, afford a permanent red dye. Woollen cloth, impregnated with solution of corrosive sublimate, and dipped in watery solution of the colouring matter acquires a red tinge which soap does not remove; and calico and linen may be dyed of the same colour by the same means, except that the solution of the colouring matter should contain ammonia. The difficulty of washing out the stains of blood is well known, and has often been the means of detecting the murderer. There is, however, no doubt that iron exists in the red globules of the blood; for, when they are burned to ashes, it has been found that one half the weight of the ashes is oxide of iron. The other ingredients of the ashes are lime, phosphoric acid, and carbonic acid. It is scarcely credible, that 1 grain of oxide of iron can communicate to 40 ounces of blood the intense hue which it possesses: yet, according to Pearson, this is the ratio of iron contained in it; and the estimate of Berzelius differs very little from this. Professor Wurzer has lately detected traces of manganese in the blood.

What the cause of the coagulation of the blood may be, is unknown. Some affirm that exposure to oxygen retards coagulation; others say it accelerates it; others, again, deny any effect to it. It happens in a vacuum; and, it has even been said, more rapidly. The previous health of the animal affects the celerity of coagulation: the less intense the powers of life, the more speedily the blood coagulates. It is found, that passing two ligatures round a vein, at a distance from each other, so as to include and confine a quantity of blood, pre-

serves it in a semifluid state for a length of time. And we know that the blood drawn by leeches, and retained in their bodies for months, will be disgorged in the same semifluid state. During fainting, in drowned persons, and those killed by lightning, the blood does not coagulate. The last fact has been questioned by Dr. Scudamore; but, as I think, on very insufficient grounds. Coagulation is prevented by agitation, although the fibrin separates; or by commixture with solutions of certain alkalies and salts, although other salts and several acids promote it.

The serum of blood coagulates when heated to 156° or 160°, nearly in the same manner as the white of an egg, but the colour is not a pure white. If the serum thus coagulated be cut in slices, and pressed, a fluid will exude, which is called the *serosity* of blood: it consists chiefly of water holding a little altered albumen, and a little common salt dissolved. The coagulum that remains is albumen. Serum is composed of water, salts, a little soda, and albumen. The ratio of water is 90 per cent.

In fine, it appears that blood is composed of two proximate parts — serum and crassamentum; or, as the latter is otherwise called, *cruor* or *clot*: that serum is composed of the following subproximate parts,—water, albumen, soda, and some salts of soda: and that crassamentum contains, as its constituent subproximates, fibrin, albumen, red colouring matter, a little iron, and, as some say, a little carbonic acid.

In the body of an animal, a variety of fatty substances exist: some of them, at common temperatures, are very hard, as tallow; others are soft-solids, as hog's lard, butter; and others are fluid, as oils. In the small space that can be devoted to these substances, it would be in vain to attempt a separate account of each; I shall, therefore, describe them generally, and enter a little into the nature of soaps.

Fats and fixed oils were considered as homogeneous proximate principles of animals and plants, until the

researches of Chevreul and Braconnot demonstrated that they are mixtures of several. Chevreul, in his early researches, found, that by heating fat in alcohol it dissolved; and that, as it cooled, a portion separated in crystals: another portion did not crystallise; it remained dissolved; and, by distilling off the alcohol, the uncrystallisable matter was obtained in the form of an oily fluid. The crystallisable matter he called *stearine;* the oily fluid, *elaine.* Braconnot, without being aware of Chevreul's experiments, effected the same separation by a mechanical and more simple method. He wrapped up lard in many folds of blotting paper, and applied pressure: the paper absorbed a portion, but left a residuum, which, when purified by being melted in oil of turpentine, cooled, and again subjected to pressure in blotting paper, was a dry, brittle, inodorous, semitransparent mass, of a granular texture. It softened with difficulty by the heat of the fingers: it was scarcely soluble in boiling alcohol: the blotting paper, when boiled in water, gave out what it had absorbed; it was a liquid oil; 100 parts of pork lard afforded 62 of this oil, and 38 of the suet. The suet described by Braconnot seems not to be the same as the crystallised substance obtained by Chevreul; for the former was insoluble in alcohol, and the latter was obtained by crystallisation of its alcoholic solution. Braconnot, however, found that when his suet was acted on by an alkali, it was decomposed into an oil and adipocere, both of which were soluble in alcohol; this adipocere, therefore, is probably identical with Chevreul's crystals.

Braconnot has shown that various fixed oils, by being frozen and pressed in blotting paper, may be separated into stearine and elaine. The stearine was white, brilliant, inodorous, insipid, and firm; 28 parts were obtained from 100 of olive oil; and it required the temperature of 68° to melt it.

Chevreul next proceeded to investigate the nature of various other fatty bodies, and succeeded in establishing the existence of several new animal proximate principles.

In butter he discovered an oily liquid, which, at 32°, does not solidify. It is soluble in boiling alcohol, but not in water: it has the peculiar smell of butter, and is sometimes white, sometimes yellow: to this he gave the name of *butyrine.* From spermaceti he separated a crystallisable matter, which he called *cetine:* from porpoise oil he procured an oil very soluble in hot alcohol, denominated *phocenine:* and, in sheep's and deers' fat, he discovered *hircine*, a peculiar oil.

When soap, composed of lard and potash, is diffused through a large quantity of water, Chevreul ascertained that a portion dissolved; and another portion, being insoluble, was deposited in pellets of a brilliant whiteness, resembling mother of pearl. This insoluble portion was dried, and digested, in a large quantity of water, at about 60°, for ten days, during which time it had filled up. The liquid was then filtered; the insoluble portion was well washed, dried, and digested in alcohol of 0·820: part dissolved, and part did not. Muriatic acid being added both to the alcoholic solution and the portion insoluble in alcohol, a fatty substance, in both cases, separated, which was soluble in boiling alcohol, and was deposited in crystals as the solution cooled. When well purified from alkali that obstinately adhered to it, it was a tasteless, pearly white substance, lighter than water: it melted into a colourless liquid at 133°; and, when cold, crystallised into brilliant white needles. It was soluble in boiling alcohol, but was deposited in crystals as the solution cooled. To this substance, on account of its resemblance to pearl, Chevreul, at first, gave the name of *margarine*; but finding that it reddened litmus, and decomposed alkaline carbonates, he called it *margaretic acid*,—a name since changed to *margaric acid.*

The two portions of muriatic acid that had been added to the original alcoholic solution, and its insoluble residuum, were next examined: the portion which acted on the soluble part had taken up one twelfth of its weight of potash, while that which had acted on the inso-

luble matter contained very small traces of alkali. This was the cause of the difference of solubility. It appeared that margaric acid combines with potash in two proportions,—forming a margarate and bimargarate of potash.

The original soap of lard and potash, when diffused in water, had partly dissolved; that which did not dissolve being the portion from which the margaric acid was obtained. The soluble portion was decomposed by tartaric acid; and a substance was thus separated, possessing acid properties: when sufficiently purified, it was very soluble in alcohol, insoluble in water, fusible at a low degree of heat, and crystallisable. Its colour is yellowish; its smell often rancid; its appearance, when liquid, oleaginous: it powerfully reddens litmus, and combines with alkalies and earths. This is an acid *sui generis*; and Chevreul gave to it the name of *oleic acid*. Thus, both margaric and oleic acids combine with alkalies and earths, forming salts, which are commonly denominated soaps.

During these investigations, Chevreul observed, that sometimes what he conceived to be margaric acid, containing a less ratio of oxygen, was obtained, and that it manifested properties somewhat different. At length he ascertained that it is a different substance, and he gave it the name of *stearic acid*. It is produced at the same time, in the same manner, and from the same substance, as margaric acid: they are both formed from stearine. But margaric acid melts at 140°, while stearic acid requires 18 degrees higher.

Chevreul next proceeded to investigate the results which the different other fatty substances, discovered by him, would present during saponification. When butter was converted into soap, by combination with an alkali, decomposed by means of an acid, and the resulting matter put through various other processes, he obtained, in a separate form, no less than three acids, each possessing distinguishing properties: the first he called *butyric*; the second *caproic*; and the third *capric*. The

two last were so named because they are procurable from the butter of the goat as well as of the cow. Beside these acids, others were discovered, which he denominated *phocenic* and *hircic*; being derived from phocenine and hircine.

It appears from these researches, that fats and oils do not, in their natural state, contain acids, as ready formed constituent parts; but that, when the fat or oil is formed into a soap, by combination with an alkali or earth, a change is produced in the constitution of the different fatty principles above-named, which determines the formation of the acids. As soon as the acids are formed, they unite with the alkali, or earth, which had been instrumental in generating them, by decomposing the fatty matter: and the salts, formed by the union, remain mixed, or loosely combined, and form soap. Thus, hard or common soap is made by combining soda with oil; and it is to be considered as consisting of margarate, stearate, and oleate of soda. Soft soap is made by combining potash with oil; and it is to be considered as composed of margarate, stearate, and oleate of potash. It is also to be understood, that in the oil, previously to combination, there was not one of the three acids present; they being the result of the chemical action of the alkali on the stearine and elaine, of which oil is composed.

It should here be mentioned, that when tallow, or hog's lard is distilled in a retort, by a brisk heat, an acid of a peculiar nature distils over, along with some acetic acid and water. It has obtained the name of *sebacic* acid. It is crystallisable, and enters into various combinations; but is perfectly different from those above described.

CHAP. IV.

COMPOUNDS OF ACIDS WITH METALLIC OXIDES AND NON-METALLIC ALKALIES.

THE affinity which acids manifest for metallic oxides, including alkalies and earths, has been explained in various parts of this volume. The resulting substance is called a salt. The number of salts now known to chemists is immense, and such as precludes the possibility of giving even the shortest description of them in so small an elementary work as this. All that can here be done, is briefly to notice the circumstances under which the acids combine with the alkalies, metallic and non-metallic, the metallic oxides, and those formerly called earths.

The generality of acids enter into combination without undergoing any change; and form a salt in which the acid exists, just as it did while insulated, so far as composition is concerned. Others not only suffer decomposition themselves, when they combine, but effect the decomposition of the base, if it be a metallic oxide; and various substances result. Of the first class are the following; and to form them, all that is required to be done, is to saturate the respective acids with the necessary base.

Acids.		*Salts.*
Nitric		Nitrates.
Carbonic		Carbonates.
Sulphuric	for	Sulphates.
Hyposulphuric		Hyposulphates.
Selenic		Seleniates.
Iodic		Iodates.
Phosphoric		Phosphates.
Hydroxanthic		Hydroxanthates.
Sulphonaphthalic		Sulphonaphthalates.

And all the vegetable acids,

When the acid ends in the syllable *ic*, the salt formed from it is made to end in *ate*. When the acid terminates in *ous*, its salts are distinguished by the termination *ite*. Thus,

Sulphurous Selenious Hypophosphorous Hyposulphurous	enters into combination, and forms	Sulphites. Selenites. Hypophosphites. Hyposulphites.

Sometimes the insulated acid cannot be directly saturated by a base, without occasioning decomposition of the acid; yet, by indirect means, its salts may be produced. Thus, if we attempt to saturate hyponitrous acid with a base, the acid is resolved into deutoxide of azote and nitric acid. By boiling 10 parts of nitrate of lead with 7·8 of metallic lead, we obtain a compound of hyponitrous acid and lead, which, if mixed with a bisulphate of the base required, affords, by double decomposition, a hyponitrite of that base. Some acids do not combine with bases at all, being decomposed when presented to them, and no indirect means being known of forming them; although, in such cases, they do not decompose the base. This happens when bases are presented to nitrous and chloriodic acids; hence, we have neither nitrites nor chloriodates. The same observation is applicable to several other acids, but with this additional circumstance, — that the bases, if metallic as well as the acids, are decomposed; and that compounds are formed, in which neither the original acid nor base exists. As the phenomena attending the production of such compounds are of great interest, it will be necessary to make some observations on them more in detail.

Until about twenty years since, muriatic acid was supposed to consist of an unknown base combined with oxygen; and it was thought that it combines with bases simply by saturating them.

When muriatic acid is poured into solution of potash, it was thought that muriate of potash resulted; and that

when the solution was evaporated, and crystals formed, these were still muriate of potash. The first position is still admitted to be true by some chemists: but they conceive that, in the act of crystallising, the salt is decomposed,—the hydrogen of the muriatic acid combining with the oxygen of the potash to form water; and the liberated chlorine and potassium uniting to form chloride of potassium, — this being the substance obtained by crystallisation, and not muriate of potash. Others admit that the resulting salt is a combination of chlorine and potassium; but they imagine that it had the same constitution while it was in solution, and that the decomposition of the muriatic acid and the potash took place at the moment of mixture. According to the first opinion stated, when chloride of potassium is dissolved in water, it is also decomposed, as well as some of the water; the hydrogen of the water and the chlorine form muriatic acid, while the oxygen of the water and the potassium form potash, which combines with the muriatic acid. Thus, according to this view, there could not exist a solution of chloride of potassium; for water converts that salt into muriate of potash, and muriate of potash could not exist in the solid state, as crystallisation converts it into chloride of potassium.

What has been here said of chloride of calcium, is applicable to all the combinations into which muriatic acid and a metallic oxide have been supposed to enter; and it has been a question amongst chemists, whether or not any such class of salts as metallic muriates exist. It is universally allowed, that, when muriatic acid saturates ammonia, the resulting crystallised salt is a real muriate, for ammonia neither contains a metal nor oxygen; and, therefore, no such changes as those described above can take place. The same observation should extend to the combinations of muriatic acid with the long list of alkalies, consisting of oxygen, hydrogen, carbon, and azote, to which vegetable chemistry is every day adding. There is no reason to suppose that any

other change takes place, in such cases, than the mere formation of a muriate.

There are other acids, concerning the combinations of which with metallic oxides, analogous doubts exist, because hydrogen constitutes an element in their composition; these are hydrocyanic, ferrocyanic, hydriodic, hydrobromic, sulphocyanic, and hydrofluoric. To all of them the same mode of reasoning applies: it is accordingly supposed by some, that when they are presented to a metallic base, decomposition of both the acid and oxide takes place; and that the result is water, with a cyanide, a ferrocyanide, an iodide, a bromide, a sulphocyanide, or a fluoride of the metal. According to the other view, a simple union takes place, and we have hydrocyanates, ferrocyanates, hydriodates, hydrobromates, sulphocyanates, and hydrofluates. In the case of ammonia and the vegetable alkalies, nothing beyond simple union is supposed to take place.

There is a fact relating to the salt resulting from the combination of hydrocyanic acid with potash, which deserves notice, as it applies by analogy to all the other cases. If a plate of copper be immersed in its solution, potassium is precipitated, which, reacting immediately on the water, evolves hydrogen by effervescence.* How is this to be explained, if the original salt was a hydrocyanate of oxide of potassium? Can it be supposed that copper could take oxygen from a substance which attracts it so powerfully as potassium?—and what other allowable cause can be assigned for the appearance of hydrogen? But if we suppose that the original salt was a cyanide of potassium, it is nothing surprising that potassium should abandon cyanogen for oxygen, when the change is aided by the affinity of nascent cyanogen for copper.

On the whole, it may be concluded that much doubt hangs over the nature and properties of the compounds which have been just described. My opinion is, that, of the two views which have been taken, that which is less

* Thomson's Chemistry, 1831, vol. ii. p. 867. et alib.

encumbered with the supposition of complex decompositions and recompositions is that which denies the existence of the hydrogen acid combinations with metallic oxides, whether in the solution or in the solid state, and considers them as compounds of a metal with the hydrogen acid radical.

Some observations remain to be made on the compounds of sulphur and hydrogen. It has been shown (page 206.) that these elements combine in two proportions, and form acids, called sulphuretted hydrogen, and bisulphuretted hydrogen: their combinations with bases have been called *hydrosulphurets* and *hydroguretted sulphurets*. Ever since it was ascertained that an alkaline or earthy sulphuret is a combination of sulphur with the metal of the alkali or earth, and not a compound of sulphur with an oxide of that metal, as was once supposed, it was believed that when a sulphuret, suppose of potassium, containing more sulphur than what constitutes a protosulphuret, is dissolved in water, it is decomposed, and decomposes a portion of the water. The hydrogen of the water combines with the sulphur in two proportions, forming the above-mentioned two acids, both of which combine with potash, formed by union of oxygen from the water with the potassium. Two salts result, which may also be formed by other means. The hydrosulphuret may be formed by transmitting sulphuretted hydrogen through solution of potash; and the hydroguretted sulphuret may be produced by digesting the former on sulphur, without heat, and filtering. From these salts, acids separate the sulphuretted hydrogen by effervescence, and the bisulphuretted hydrogen by deposition in the form of an oily tenacious liquid; the potash combining with the acid added.

When sulphate of potash, mixed with charcoal, is heated to whiteness, both its elements give up their oxygen to form carbonic acid with the charcoal; the potassium and sulphur then form protosulphuret of potassium. If dilute sulphuric acid be poured on this, some water is decomposed, the oxygen of which con-

verts the potassium into potash; and this, with the sulphuric acid, reproduces the original sulphate of potash: but the hydrogen of the decomposed water is sufficient to saturate all the sulphur, and the resulting sulphuretted hydrogen effervesces off; there is, therefore, no other product. But had the original sulphate of potash and charcoal been exposed to a red instead of a white heat, some potash would have escaped decomposition; hence, the potassium evolved would be insufficient to eliminate as much hydrogen from the water of the dilute sulphuric acid as would convert all the sulphur present into sulphuretted hydrogen, and hence some sulphur would be precipitated.

The same sulphuret of potassium may be generated by heating potassium in sulphuretted hydrogen; the sulphur forms sulphuret with the potassium, and hydrogen is disengaged. If the sulphuret of potassium be heated in more sulphuretted hydrogen, they combine without decomposition, and the result is a solid hydrosulphuret of sulphuret of potassium. Exactly the same solid is produced by heating carbonate of potash in an excess of sulphuretted hydrogen; the latter expels the carbonic acid, its hydrogen deoxidates the potash, and the metal combines with the liberated sulphur: the sulphuret of potassium thus formed combines with sulphuretted hydrogen as before.

When this salt is thrown into water, we are at a loss to know what happens. It may merely dissolve; or some water may be decomposed; its oxygen, with the potassium, forming potash; its hydrogen, with the sulphur of the potassium, forming a quantity of sulphuretted hydrogen, additional to what was originally present. The sulphuretted hydrogen, now doubled, may combine with the potash, forming a solution of bihydrosulphuret of potash, which, in crystallising, may undergo decomposition: the hydrogen and oxygen, originally furnished by the decomposed water, uniting and recomposing water; while the sulphur and potassium, with which these elements had been combined, recompose sulphuret

of potassium, this re-uniting with the original sulphuretted hydrogen.

The bihydrosulphuret of potash above mentioned is the salt commonly called hydrosulphuret of potash, and prepared by passing a stream of sulphuretted hydrogen through solution of potash. This last method of preparing it might be explained in two ways, conformably to the foregoing two views. Either the gas is merely absorbed, or the potash and half the gas are decomposed at the instant of meeting; the hydrogen, by taking oxygen from the potassium, producing potash, and leaving its sulphur to combine with the potassium, and form sulphuret of potassium, which then unites with the remaining undecomposed half of the sulphuretted hydrogen, leaving hydrosulphuret of sulphuretted potassium in solution.

Although the explanations here given have been confined to sulphuretted hydrogen and potash, they apply equally to any other metallic base. When ammonia or a vegetable alkali is the base, we must suppose that this acid gas merely combines, without suffering or occasioning decomposition.

PART III.

PHENOMENA PRESENTED DURING SOME REMARKABLE CHEMICAL CHANGES.

CHAP. I.

OF SOME PROCESSES CONNECTED WITH ANIMAL LIFE.

ALTHOUGH it is not my intention to enter into explanations of vital functions in general, there are two animal processes so intimately connected with, if not dependent upon, chemical changes, that they appear to fall within the province of the chemist almost exclusively. There are others which seem to have been so little illuminated by the lights of chemistry, that they might just as well be surrendered altogether to the physiologist. The subjects of respiration and animal heat shall occupy the two succeeding sections.

SECTION I.

RESPIRATION.

The blood is distributed by the arteries to all parts of the body, and is returned by numerous veins, which, by frequent junctions, become larger, and at length terminate in two trunks, called the vena cava superior, and vena cava inferior: these, meeting at the heart, discharge into the right auricle, from which the blood is propelled into the right ventricle, and hence into the pulmonary artery, which ramifies in a vast number of minute branches through the air cells of the lungs. After being exposed in these delicate vessels almost to the direct action of the air inspired into the lungs, the blood is returned by the pulmonary veins to the left auricle, and

hence to the left ventricle, from which it is dispersed through the aorta to all parts of the body. It is while passing through the minute and numerous ramifications of the pulmonary artery and pulmonary veins, and their capillary junctions, that the blood loses its dark shade, assumes the florid red hue which it is found to possess in the arteries, and acquires its nutritious qualities. During the circulation, it loses its vermilion colour and its nutritious qualities, by supplying the waste of materials throughout the whole body; and when it has returned into the veins, it has once more become dark coloured. The change of venous into arterial blood is the essential phenomenon constituting respiration; it is by this change that the blood is qualified to support life.

What the nature of this change may be, is a subject involving much difficulty and uncertainty. The process by which it is effected must be of great consequence to the animal: for one of the chief uses of that complex apparatus, constituting the organs of circulation, is to expose the mass of the blood, amounting, as some affirm, to 33 pounds, extended to a vast surface in the capillaries of the lungs, to the action of the atmosphere, about 23 times every hour; for such is the calculated velocity of the circulation. The following is an abstract of the different theories which have been advanced to explain the nature and uses of the process of respiration.

Lavoisier conceived that the oxygen of the air drawn into the lungs during inspiration, meeting hydrogen and carbon, which exist in the blood, combines with both, either in the lungs or during the circulation; carbonic acid and water result, and these are expired. He conceived that the azote neither acts nor is acted upon.

Crawford taught that the blood receives what he called hydrocarbon in the capillaries; and that it is the presence of this in venous blood, which constitutes the difference between it and arterial blood. The oxygen of the air inspired, combines with the hydrocarbon in the lungs, and forms carbonic acid and watery vapour. In

consequence of this abstraction of hydrocarbon, the venous blood is reconverted into arterial. It is not easy to perceive any real difference between this, and the theory of Lavoisier.

I have not had an opportunity of seeing the original of M. Lagrange's theory; what follows, is the account given of it by Hassenfratz. The blood, in passing through the lungs, dissolves oxygen abstracted from the air inspired: the blood, holding this oxygen, is transmitted through the arteries, and thence to the veins; during its passage, the oxygen, by little and little, forsakes its state of dissolution, and partially combines with the carbon and hydrogen of the blood, forming water and carbonic acid; the latter of which is disengaged as soon as the venous blood leaves the heart to enter the lungs.

Hassenfratz has supplied some parts of the detail of this theory, and has supported them by experiment. It was ascertained by Priestley and others, that venous blood, by exposure to oxygen, is rendered bright red; that, by remaining for some time thus exposed, it gradually loses its florid hue, even although they are shaken together; and that blood, exposed to any gas not containing oxygen, is rendered dark. Hassenfratz explains these facts, by supposing that the bright red colour of arterial blood is occasioned by its holding oxygen in solution; and that when the oxygen abandons the blood, in order to combine with the carbon and hydrogen present, the blood loses its bright red colour, and becomes dark: it is then venous blood. Corresponding with this explanation, he ascertained that chlorine (which indirectly supplies oxygen), mixed with venous blood, immediately renders it very dark coloured; a phenomenon, in his opinion, attributable to the facility with which chlorine supplies oxygen in a state ready for immediate combination with carbon and hydrogen, while the oxygen of the atmosphere, being gaseous, combines with difficulty. Chlorine does in an instant, what common air can only do by long continued contact.

These theories differ very little from each other. In

all of them the error is committed, of supposing that water is *generated* in the lungs; whereas it is merely exhaled from the mucous membrane which lines the mouth and pharynx. That no union takes place between the oxygen of the air and hydrogen existing in the blood, is proved by the fact, that although moisture is always found in the breath, the quantity of oxygen which disappears is, at times, almost exactly equal to the carbonic acid by which it is replaced; and we must suppose that the origin of the moisture is always the same.

It is not explained, in any of these theories, what the origin of the carbon is, that is supposed by them to be constantly renewed in the blood: this deficiency has been supplied by Drs. Thomson and Murray, in their respective systems of chemistry. Dr. Thomson says, "It appears, from the most accurate observations hitherto made, that neither chyle nor lymph contain fibrin*, which forms a very conspicuous part of the blood: this fibrin is employed to supply the waste of the muscles, the most active parts of the body; and, therefore in all probability, requiring the most frequent supply. Nor can it be doubted that it is employed for other useful purposes. The quantity of fibrin in the blood, then, must be constantly diminishing; and, therefore, new fibrin must be constantly formed. But the only substances out of which it can be formed, are the chyle and lymph, neither of which contain it: there must, therefore, be a continual decomposition of the chyle and lymph going on in the blood vessels, and a continual new formation of fibrin. In what manner the chyle, or a part of it, is converted into fibrin, it is impossible to say; but we can see at least that carbon must be abstracted from that part of the chyle which is to be converted into fibrin. Hence, as the process of blood-making advances, there must be a greater and greater redundancy of carbon in the liquid: we may conclude, therefore, that one great use of respiration is to abstract this carbon, by forming with it carbonic acid."

* At least the quantity of fibrin is quite inconsiderable in blood.

Dr. Murray gives the following account: — "The blood is the source whence the animal products are formed: this expenditure is supplied by the chyle, — a fluid less completely animalised than the blood. The peculiar character of animal matter, with regard to composition, is a large proportion of nitrogen, and a diminished proportion of carbon: it may be, therefore, inferred, that in the extreme vessels, where the animal fluids and solids are formed, the general process will be the separation from the blood of those elements of which animal matter is composed; and that, therefore, carbon, which enters more sparingly into its composition, will exist in the remaining blood in an increased proportion. This is, accordingly, the general nature of the conversion of arterial into venous blood. Nitrogen, hydrogen, and other elements, are spent in the formation of new products; and the proximate principles of the blood remain, with an increased proportion of carbon. In this state it is exposed to the atmospheric air in the lungs — the oxygen of which abstracts its excess of carbon, and forms the carbonic acid expired; and this constitutes the conversion of venous into arterial blood."

The foundation of Thomson's explanation is the position, that carbon must be abstracted from that part of the chyle which is to be converted into fibrin. Unfortunately, we do not possess comparative ultimate analyses of chyle and fibrin; and hence the proof of the above position rests on the fact, that carbon is taken up by oxygen in the lungs, which is the phenomenon to be explained. It is possible that chyle may sometimes contain a greater ratio of carbon than fibrin does. Dr. Marcet showed that the chyle of dogs fed upon vegetable diet, afforded three times more carbon than that of dogs fed on animal food: but a theory of the origin of carbon in expired air must account for its appearance under all circumstances of diet. Murray's explanation depends on the truth of the position, that "the peculiar character of animal matter is a large proportion of nitrogen, and a diminished proportion of carbon." Hence he considers,

that, as "all animals live, directly or indirectly, on vegetable matter," the chyle will be a "fluid less completely animalised than blood;" which must mean, that it will partake more of the vegetable constitution, from which it is ultimately derived. It does not appear to me, that the indirect origin of food of animals in vegetable matter has any connection with the subject; for a vegetable becoming animalised, cannot affect the chyle produced by assimilation of such animalised matter. But that one of the peculiar characters of animal matter is its containing a diminished ratio of carbon, is a position which not only has never been established by experiment, but seems contradicted by most of the facts with which we are acquainted. We do not know the relative quantities of fibrin, gelatine, and albumen, which chiefly constitute muscle; but it is of less consequence, as the ratio of carbon in each of these three proximate principles is not very different. Were muscle composed of equal parts of these proximate principles, the average ratio of carbon would be about 51·4 per cent.: this is precisely the quantity of carbon in beech-wood. Wheat flour does not contain, at most, above 45 per cent. of carbon; potatoes contain but 37·4 per cent.; and, generally, vegetable proximate principles contain less than 50 per cent. of carbon, and many of them much under this ratio. These considerations render Dr. Murray's position very questionable.

It appears to me, that, notwithstanding the industry with which the subject has been prosecuted by modern chemists and physiologists, the theory of respiration stands pretty much in the same way as it was left by the modification of Lavoisier's explanation, given by Lagrange: it may, therefore, be expedient to expatiate on it a little more fully.

That oxygen exerts an agency on blood, is a fact that seems proved beyond question. The experiments of Fontana and Luzuriaga show, that blood, whether arterial or venous, when shaken in contact with common air, or, better, with oxygen, imparts carbon, and con-

verts the oxygen into carbonic acid: it is, therefore, a fair presumption, that, in the body, the change of inspired oxygen into carbonic acid is effected in the same manner. In the air cells of the lungs, the oxygen may be considered as almost in contact with the blood contained in the ramifications of the pulmonary artery, and of the pulmonary veins in which they terminate; inasmuch as nothing but the exceedingly thin substance of the vessels is interposed. It was shown by Priestley, that venous blood, tied up in the thicker substance of a moist bladder, became red when exposed to air, as soon and as much as if in direct contact with the air. When the oxygen of the air is taken into the lungs, after a momentary contact, as it may be called, with the blood, it is discharged again during expiration; but part of it has combined with carbon. Concerning this combination, there have been, as was already stated, two opinions. One is, that the oxygen of the air instantly dissolves and combines with carbonaceous matter found in the blood, and immediately after is expired as carbonic acid: the other is, that the oxygen of the air is absorbed by the blood in the lungs; that it circulates with the blood throughout the whole system, during which it combines with carbon; and that, on the return of the sanguineous current to the lungs, the carbonic acid thus produced exudes through the coats of the minute vessels, and is expired. I consider the latter of these opinions the more probable, on several accounts. Fontana exposed blood to common air, during so long a space as three minutes, without producing any change; but when he *agitated* them together during the same time, carbonic acid appeared. Independently of the evidence afforded by this experiment, it might reasonably be expected that the carbon of the blood would require more than an instantaneous contact with the oxygen of the air, before a combination could take place. Such a condition would be fulfilled, if the oxygen were to circulate with the blood for two minutes and a half; for this, as far as is known, is the space of time which the whole volume of the blood

requires to travel from the lungs back again to the lungs; and this was nearly the space of time during which Fontana found it necessary to continue the agitation. If, in Fontana's experiment, actual contact of the blood with oxygen during three minutes did not evolve any carbonic acid, it would be singular if, in the lungs, carbonic acid could be formed during the time occupied by one inspiration, notwithstanding that the substance of the blood vessels and air tubes is interposed. These considerations correspond exactly with the fact stated by several respectable authorities, that carbonic acid exists in recently drawn blood; and that it may be separated from the blood, by placing it under an exhausted receiver. The statement has, certainly, been called in question; but it appears that the authorities by which it is supported, are of equal consideration with those opposed to it: and there is this additional argument in favour of it, — that it harmonises with all the facts known.

It appears to me, that to confine the office of air inspired to the mere removal of redundant carbon from venous blood, is to take a limited view of its operation; and to under-rate the utility and necessity of the complex and astonishing mechanism by which so simple an object would be accomplished. To the process of respiration, the construction of the chief parts of the animal system are subservient: if respiration be suspended, so is life: even the atmosphere is constituted in such a way as to conduce to the due performance of this function. We know the important and extensive agency of oxygen in creation: can we doubt that, in the laboratory of the body, where chemical changes are incessantly taking place, oxygen is in all parts constantly in demand? and is it not probable, that the medium of supply of oxygen to all these parts is that obvious one, which, in order to receive the supply, is presented, in hundreds of currents, to hundreds of currents of air, the absorption being promoted by the two most efficacious means, — agitation, and extensive surface?

It would contribute towards a decision of this question, were it ascertained that the air taken into the lungs loses at all times exactly the same volume of oxygen as is returned in the state of carbonic acid. A volume of oxygen suffers no change in being converted into carbonic acid. If this conversion took place equally in the lungs without any change of volume, it might then be presumed that the oxygen inspired had done nothing else than remove carbon.* Hitherto there has not been such a correspondence between the results of the experiments made on this part of the subject, as to warrant almost any conclusion that ought to influence our judgment on so difficult and important a question. The inference which seems best supported by the statements of different experiments, is, that sometimes the oxygen of the air inspired almost exactly agrees with the carbonic acid expired; this happens in the human species, and some other animals. Sometimes there is a greater volume of oxygen consumed than is accounted for by the carbonic acid: and in certain animals the difference is often considerable. It seems that, so far as the function of respiration is concerned, it matters little what animal, within certain limits, is made the subject of observation; we must suppose that, in the higher orders of animated beings, the use and nature of the function is mainly the same.

It has been found that the azote of the air inspired is sometimes returned in full volume, and sometimes is partially retained, and disappears; the quantity of it is very variable. It has been even ascertained that the quantity of azote expired sometimes exceeds the quantity which had been contained in the common air taken into the lungs; and it has been affirmed that this happens in summer, while in winter less azote is returned than is received by the lungs. This evolution of superfluous azote, no longer necessary in the animal economy, has been strikingly proved to take place, by including a guinea-pig in pure oxygen, and another in

* Its influence in producing animal heat is for the present neglected.

a mixture of oxygen and hydrogen—the ratio being that which forms water; in both cases, azote was found in the remaining gas. A pigeon confined in a similar mixture of oxygen and hydrogen also evolved azote. During the respiration of both of these animals in the mixed gas, it was found that some hydrogen was taken into the lungs, which totally disappeared. The singular fact has been ascertained, — and it is one which may yet be turned to good account by the physician, — that breathing a mixture of oxygen and hydrogen produces a tendency to sleep.

It has been found that, in the human species, different individuals consume different quantities of oxygen, and of course return different quantities of carbonic acid. The breath expired has been shown to contain from 3 to 8 per cent. of carbonic acid. Drs. Prout and Fyfe have proved experimentally, that peculiar conditions of mind or body render the quantity of carbonic acid variable. The former has shown that the quantity depends also on the time of the day: at noon it is at the maximum; it decreases until nine at night; it then remains at the minimum for six hours; and at four in the morning it begins to increase. These were the results obtained in the month of August.

The lungs are not the only egress for carbon in the human body. If a person's arm be enclosed in a bell glass full of common air, and the communication with the external air be cut off by tying a moistened bladder round the mouth of the bell glass to the arm, the oxygen of the air will in part disappear, and be replaced by carbonic acid; but it is not known how this change is effected.

The foregoing statements seem to bear out the conclusion just now arrived at, that we are really ignorant of the uses of respiration in the animal economy, and that the mere removal of carbon cannot be the duty of the air which enters the lungs. Both oxygen and azote are proved to be frequently absorbed; and, for any thing we know to the contrary, these occasional supplies

of two active gases may be just as necessary under certain conditions of the animal, as the formation of carbonic acid in the circulation (if it be there that its elaboration takes place), and the eventual elimination of carbon from the body. When additional oxygen and azote are not necessary in the body, then, probably, the inspired air is returned in full volume; having merely experienced a partial conversion of its oxygen into carbonic acid.

Section II.

MAINTENANCE OF THE TEMPERATURE OF ANIMALS.

The changes produced during respiration have been always supposed to be intimately connected with the maintenance of that elevated temperature, which distinguishes the existence of certain orders of animated beings; and much difficulty has been experienced in forming a theory of animal heat which will correspond with the facts, but hitherto without success.

Black's doctrine of latent heat afforded an explanation of the origin of animal heat. During respiration, the oxygen of the air inspired combines with carbon, and, as it was at first supposed, with hydrogen; both of these substances, in combining with oxygen, evolve some of the heat which was latent in the composition of the oxygen and hydrogen; and this heat is circulated by the blood to all parts of the body.

But it was soon perceived that, as this combination took place in the lungs, and the heat was evolved there, the lungs should not only be the hottest part of the body, but the heat would be capable of injuring these organs. In order to remove this difficulty, different explanations were offered, of which the chief are the theories of Crawford and Lagrange.

Crawford made experiments to prove that the specific heat of arterial blood is greater than that of venous. Hence, arterial blood, at the temperature of the lungs,

would contain more heat than venous blood at the same temperature ; and arterial blood, in changing to venous, would part with its excess of heat, and yet remain at the same temperature as before. If oxygen, in combining with carbon and hydrogen contained in the blood, caused the evolution of so much heat, that evolution would take place in the blood itself at the lungs. But at the same instant the blood becomes arterial ; that is, in effect, suffers an increase of its capacity for heat, absorbs a quantity of heat which does not raise its temperature, and thus removes the portion of heat that might have done injury to the lungs. In this way the blood and heat are carried to the capillaries ; where the former, by continually changing into venous blood of less capacity, parts with its heat gradually, and maintains the animal temperature equably.

Lagrange removed the difficulty, and arrived at the same object, by supposing that the heat is not disengaged exclusively in the lungs, but in all parts where the blood circulates. This follows from his theory of respiration already described. According to him, the oxygen of the air is dissolved by the blood at the lungs, and circulates, thus dissolved, in the arterial blood ; it is only when the blood is changing gradually and slowly in the great circuit of the capillaries, that the combination of oxygen with carbon and hydrogen takes place, and that the heat is developed.

Dr. Girtanner, of Göttingen, gave a modified view of this theory, which, being rendered uselessly complex, need not here be described.

Dr. John Davy, in repeating Crawford's experiments on the difference of specific heats of arterial and venous blood, obtained different results. According to the former, the difference is inconsiderable, and inadequate to sustain the object for which the experiments were instituted. It is of no consequence whether we decide in favour of the accuracy of Davy or Crawford ; inasmuch as the theory of Lagrange explains the equalisation of animal heat in a satisfactory way ; seems to

harmonise best with recently discovered facts; and thus renders the theory of Crawford, ingenious and beautiful as it is, useless.

The grand question was, what is the source of animal heat? Black supposed that the oxygen of the air inspired parts with some of its latent heat. Crawford conceived that the difference between the specific heat of oxygen and carbonic acid is the portion which is liberated during respiration, and maintains the animal temperature. But Delaroche and Berard infer, from their experiments, that this difference is trivial: they represent the specific heat of oxygen to be 0·8848, and that of carbonic acid 0·828; air being unity, and the comparision being made on equal weights of the gases. Hence it has been supposed, that so small a difference cannot be the source of the large quantity of heat present in the body. But it is between the specific heats of equal volumes that a comparison should be instituted. We then have 0·9765 as the specific heat of oxygen, and 1·2583 for that of carbonic acid: the difference is much greater than in the former case; but still the question arises, is it sufficient to account for the temperature of the body?

In answer to this question, it was maintained, on the authority of experiments by Crawford, Lavoisier, and La Place, that an animal consuming oxygen, and returning it as carbonic acid, evolves pretty nearly as much heat as that same quantity of oxygen would evolve, had it been converted into carbonic acid by the combustion of carbon in it. Chemists, however, seem to place no reliance on the measures of heat employed in these and similar experiments; and even the opposite of the inferences drawn from them have been maintained to be true.

It appears to me, that a very useful estimate may be formed in this inquiry, by reference to common experience, without the aid of any instrument or refined experiment. It is believed that a man generates about 40,000 cubic inches of carbonic acid in 24 hours; this

contains about 11½ avoirdupois ounces (11·59) of carbon. Suppose that this quantity of charcoal were burnt in common air; that the whole of the heat evolved were applied, without loss, to sustain the temperature of the human body at 98°; and that the body consists of 12 stone weight of solids, soft solids, and liquids: a considerable portion of heat is to be abstracted by the surrounding medium, and much moisture is to be vaporised in the breath, and in cutaneous perspiration. The quantity of vapour of water produced at the surface, supposing its average temperature 96°, and from the mouth, would amount to no less than 209,826 cubic inches in 24 hours, at some times; and would seldom be less than 70,000. Beside this, the expired air leaves the mouth at 90°; and a million cubic inches of air so heated leave the mouth every 24 hours. Would the combustion of 11½ ounces of charcoal afford such a supply of heat for 24 hours (that is, 211 grains per hour) as would accomplish all these objects?

Mr. Brodie, led by considerations of a different kind, has denied that there is *any* production of animal heat, in consequence of the conversion of oxygen into carbonic acid in the lungs. Having procured two rabbits of the same size and colour, he killed both by dividing the spinal marrow. Having removed the head of one, and secured the vessels of the neck by ligatures, he produced artificial respiration by means of a small bellows fitted to the trachea. The heart now contracted at the rate of 144 times in a minute; but in 100 minutes the number was reduced to 90 per minute. A thermometer had been introduced into the rectum of each rabbit, and at the beginning of the experiment both stood at 100½°. Both thermometers began to sink; but that in the rectum of the rabbit in which artificial respiration was kept up was always 2 or 3 degrees lower than the other. In 100 minutes, the former stood at 90½°, the latter at 93°. The difference throughout was attributed to the large quantity of cold air which constantly

cooled the blood circulating through the lungs of one, and not of the other: and it was shown in another experiment, that when the circulation is prevented by a ligature, the artificial respiratory process being continued, the cooling agency of the air was scarcely discoverable, because it now was confined to the air cells of the lungs, and could not affect remote parts.

Other experiments showed that, in rabbits killed by poisons, which act by disturbing the functions of the brain, the circulation may be contained by carrying on an artificial respiration; the same quantity of carbonic acid was expelled as during life; and the same change of sensible qualities of the blood took place in the two capillary systems, as would occur in the living animal. Yet in consequence of the cold air thrown into the lungs, the animal cooled more rapidly than another in which no artificial respiratory process was kept up. Mr. Brodie, therefore, argues, that if the conversion of oxygen into carbonic acid in the lungs were the cause of animal heat, the dead bodies of these rabbits should have maintained their temperature. He concludes that animal heat depends on some function of the brain.

These experiments are, however, liable to some exceptions. Although artificial respiration did not keep up the animal temperature, it might have generated some heat, which was afterwards carried off in various ways. First, the cold air thrown into the lungs, acting on the whole circulation, must have withdrawn heat in two ways; and the experiment of obstructing the circulation by a ligature, as is admitted by Mr. Brodie, did not prove that heat was not withdrawn. Secondly, no allowance was made for loss of heat by the vaporisation of water exhaled by the mucous membrane. And, thirdly, there was no allowance for loss of heat by cutaneous perspiration, which takes place, often largely, at the moment of death, and no doubt continues while the circulation is forced to continue. At least, it was not proved that these three sources of fallacy did not exist. It must be observed also, that these experiments

have not been attended with the same results in the hands of other persons; for it has been affirmed that the cooling process is rendered slower by artificial respiration. This, however, is of little consequence. Mr. Brodie's experiments prove very clearly, that animal heat is not maintained by respiration; but they do not prove that *no* heat is generated during that process.

Indeed, it can scarcely be denied, that the conversion of oxygen into carbonic acid in the lungs, is a source of some heat, as well as it would be out of the lungs. In the process of arterialisation, the blood is proved to become warmer. Majendie estimates, I know not if on the authority of his own experiments, the difference between arterial and venous blood so high as 2°; and although this difference is not great, it is quite clear that it does not represent the total heat developed during respiration.

It might, perhaps, be considered probable, that the conversion of liquid chyle into solids, to supply the waste of the body, might, during the change from fluidity to solidity, evolve the remaining quantity of animal heat. But, beside some difficulties that would attend this mode of explanation, we are prevented from adopting it by knowledge of the fact, that during some diseases there is no such conversion, for no aliments are taken into the stomach; and instead of any accession to the solids, there is a constant wasting of them: yet the heat of the body is higher than ever.

Perhaps the opinion on the subject of animal heat, in entertaining which we shall be least liable to error, is, that the elevated temperature of warm-blooded animals does not derive its origin from any one source, but from several, and that at present we know of but one. We may also suppose that chemical changes are constantly taking place in the body, through the means of which heat is extricated. But we are not enabled to assign any thing more precise as to the nature of these changes, without entering into useless or dangerous hypotheses.

CHAP. II.

OF THE SPONTANEOUS DECOMPOSITION OF VEGETABLE AND ANIMAL MATTER.

By the word fermentation*, modern chemists understand the spontaneous decomposition which animal or vegetable matter undergoes when placed under proper circumstances; the most remarkable result of which is, either alcohol, acetic acid, or a putrid smell. The production of these different results gives origin to three distinct stages of the process, each characterised by different phenomena. All fermentable substances, however, do not proceed through each of these changes, even when the circumstances are favourable: but there are some good instances in which the stages are distinct and consecutive. If grape juice be exposed to a moderate temperature, it soon begins to effervesce, and loses its transparency; a viscid scum rises to the surface; the taste changes from sweet to *vinous;* and, under proper management, the liquor is converted into wine. Solution of sugar and all sweet liquids are capable of undergoing similar changes, and of being converted into a kind of wines. The process by which these changes are effected, is, on account of the nature of the product, called the *vinous fermentation,* and the result of it is the formation of *alcohol.*

If the liquor which has undergone the vinous fermentation be exposed to the temperature of about 75°, it from being transparent again appears somewhat muddy; the taste changes to sour, for the alcohol is now changed into vinegar; and from *acetum,* the Latin for vinegar, this stage is called the *acetous fermentation.*

Vinegar, when long kept, loses its acidity and its transparency: it exhales a putrid smell; and has now undergone its last stage, or the *putrefactive fermentation.*

* A much fuller account of the process of fermentation will be found in the Cabinet Cyclopædia, Vol. I. of Domestic Economy.

When wheaten flour is made into dough with water and a little yeast, it undergoes the vinous fermentation; carbonic acid is evolved, which puffs up the dough into a light sponge; and alcohol in small quantity is evolved. A patent has been taken out for an oven, which, in baking the bread, condenses the alcohol. I examined some of the alcohol thus produced, and found both it, and the bread which afforded it, to be, as I conceived, of excellent quality.

There are several conditions necessary to the production of fermentation: water must be present in all cases; there must be a temperature above 32° at the lowest; a fermentable substance, and a ferment, are also necessary.

Vinous fermentation.—In order to produce the vinous fermentation, the only fermentable substance known is sugar, in some one or other of its modifications. A solution of common sugar, starch sugar, fruit sugars, as contained in the different fruits, or the saccharine matter of malted grain of any kind, will answer the purpose perfectly. In some cases, sugar does not exist ready formed, although the vinous fermentation may be excited: but in all such cases, the elements of sugar are present; and during some stage in the process, sugar is produced from them. It was discovered by Kirchoff, that if potato starch, and gluten from grain, be mixed with hot water, and allowed to act on each other, the mixture, at first not in the least sweet, eventually becomes so, because the starch is converted into sugar. This explains the fact, that in the process of the distiller a mixture of malt and raw corn, when mashed with warm water, and fermented, affords even more alcohol than would have been obtained had the raw corn been malted. In the raw corn there was both starch and gluten.

It is here necessary to explain the nature of *malt*: any kind of grain, such as barley, bere, oats, wheat, millet, rice, maize, or rye, by being made to germinate, and the germination immediately stopped, will be thus converted into malt. By the process of germination, the starch of the grain is spontaneously converted into sugar,

intended by nature as the food of the embryo plant. The instant the sugar is formed, the process should be stopped, as otherwise it would disappear again. The germination is checked by drying the grain. When barley is to be malted, it is first steeped in cold water: after a time, the water is drained off; the barley is spread out in a deep heap: it soon becomes warm, owing to the chemical action which forms sugar in it; the rootlets and future stem shoot. When this happens, the grain is spread on a heated kiln until it is quite dry. The result is malt. When grain has been made to germinate, and the further growth of the embryo plant is checked by drying, "its vital principle is extinguished for ever."*

The ferment is the body which possesses the power of commencing the fermentation; and once commenced, it proceeds without further assistance. Its presence is so necessary, that a solution of pure sugar will not ferment. There are many substances, however, which combine in themselves both a ferment and a fermentable matter. Thus, impure sugar, when dissolved in a sufficient quantity of water, will ferment almost perfectly: the juice of the grape, gooseberry, and some other fruits, contain both abundantly. The ferment commonly used by brewers, distillers, vinegar makers, and bakers, is *yest* or *barm*,—the scum which rises to the top, and afterwards falls to the bottom, of those vessels in which the fer-

* The passage marked above by inverted commas is taken from the first volume of Domestic Economy, written by me for the Cabinet Cyclopædia. It was some time since brought forward as evidence in a revenue trial, in such a manner, that I was induced to make experiments with a view of ascertaining how far those authors, from whom I took the statement, were correct.

I procured several samples of *pale* malt of the best quality from different corn factors and brewers. They were sown in different drills about the beginning of April, along with a drill of barley. The barley grew in course; but for three weeks there was little or no appearance of the malt. The malt then sprang up abundantly in all the drills, and, at length formed good ears of corn. The only difference was, that the malt, in shooting, forming ears, and ripening, was always three weeks later than the barley.

Next year I procured from an eminent corn factor some pale malt, picked grain by grain, each of which he pronounced to be *perfectly* malted. These were sown in drills as before. *Not one grain ever germinated.* The year after, the experiment was repeated on picked grains, with the same result. We may therefore infer, first, that in *perfect* malt the vital principle is extinct; second, that the process of malting is very imperfectly practised; and, third, that the evidence afforded by the growth of suspected malt, so often brought forward by excise officers at revenue trials, ought to be considered as proving nothing.

mentation of infusion of malt is conducted. Little is known of the nature of ferments; yest has been supposed to be gluten; gluten has been found capable of producing fermentation, and it is known to exist in grapes and gooseberries. If grape juice be deprived of its gluten by boiling and filtration, it will not ferment.

Alcohol is composed of oxygen, carbon, and hydrogen; the oxygen in it, if saturated with as much of the hydrogen present as would form water, would leave exactly as much hydrogen as would saturate the carbon present, so as to form olefiant gas. Hence alcohol may be said to be a compound of water and olefiant gas; or the same may be expressed by saying that it is a compound of oxygen, carbon, and hydrogen. If its composition be expressed in the latter way, it will stand thus: — Oxygen 34·8341, carbon 52·1035, hydrogen 13·0611 = 100 grains: if in the former way, thus: —

Vols or cub. in.		Grains.		
100	vapour of water consist of	ox 16·9576 hyd. 2·1197	specific gravity	0·6191
100	olefiant gas consist of	hyd 4·2394 carb 25·3640	specific gravity	0·9708
200	condensed into 100 of alcohol vapour weighing - -	48·6807	and of specific gravity	1·5799

Hence, the specific gravity of the vapour of alcohol, at 60°, is 1·58; 100 cubic inches of the vapour weigh 48·68 grains; and 48·68 grains of pure liquid alcohol, when resolved into its two constituents, would consist of 100 cubic inches of vapour of water, and 100 of olefiant gas. We have now to enquire how alcohol is formed from sugar.

The composition of sugar is so differently stated by chemists, that the analyses given can be considered as little better than good approximations. According to Berzelius, 100 parts consist of carbon 44·2, oxygen 49·015, hydrogen 6·785. Dr. Ure says, carbon 43·38, oxygen 50·33, and hydrogen 6·29, in 100. Gay-Lussac and Thenard give the numbers thus: 42·47, 50·63, and 6·9. Dr. Prout gives carbon 42·85, and

the elements of water 57·15. Were we to consider sugar composed of carbon 39·9315, oxygen 53·3941, hydrogen 6·6744, the following would be the constitution by volume of 95·278 parts; and the reason for selecting that number of parts will presently appear.

	Grains.		Cubic in.
Carbon vapour	38·0460	being in volume	300 or 3 vols.
Oxygen - -	50·8729	- -	150 or $1\frac{1}{2}$
Hydrogen -	6·3591	- -	300 or 1
	95·278	resolvable into	750

Now, according to Gay-Lussac (*Annales de Chim.* xcv. 316.), 100 parts of sugar, when made to undergo the process of fermentation, are converted into 51·34 parts by weight of alcohol, and 48·66 of carbonic acid: hence, 95·278 grains would afford 48·915 of alcohol, and 48·363 of carbonic acid. If, in order to make the analyses correspond with the theory of volumes, and the specific gravities of the gases as determined in this work, for reasons assigned, we alter these numbers to 48·6807 alcohol, and 46·5973 carbonic acid, the following scheme expresses the changes which happen during the conversion of sugar into alcohol: —

	Sugar. Cub. in.		Alcohol. Grains.	Carbonic acid. Grains.
Carbon vapour	200	weighing	25·3640	
	100	- -	-	weighing 12·6820
Oxygen -	50	weighing	16·9576	
	100	-	-	weighing 33·9153
Hydrogen -	300	weighing	6·3591	
	750	converted into	48·6807	and 46·5973

By comparing this scheme with the composition of alcohol given above, it will appear that the analysis of the 48·6807 grains of alcohol is the same. And from all these statements it may be collected, that 95·278 grains of sugar (which consist of gases amounting to 750 cubic inches) are converted by fermentation into 46·5973 grains of carbonic acid, and 48·6807 grains of

alcohol, consisting of 100 cubic inches of the vapour of water, and 100 cubic inches of olefiant gas. These calculations correspond so accurately with the facts, that I do not hesitate to adopt them. We may briefly express the change thus: some of the carbon and some of the oxygen combine to form carbonic acid, which exhales during the fermentation; while the remainder of the carbon, the remainder of the oxygen, and the whole of the hydrogen, combine to form alcohol. The fermentation takes place independently of the elements of the atmosphere; the product is even larger when the atmosphere is excluded. In the case of grape sugar, Gay-Lussac found that, at the beginning of the process, the absorption of a little oxygen was necessary.

Acetous fermentation. — When a liquor that has already undergone the vinous fermentation, is exposed for a length of time to a temperature of 75°, the heat rises 10° or 15°, a hissing is heard, carbonic acid is generated, the oxygen of the atmosphere being absorbed, and the vinous taste gives place to an acid one. The alcohol which the liquor contained is now converted into vinegar. Floating shreds make their appearance, and are deposited as a gelatinous magma. These are the changes which take place when a large quantity of vinous liquor is acted upon: if the quantity be small, no change is observable but gradual souring.

In order to form vinegar, it is not necessary that the liquid employed should have undergone a distinct and separate vinous fermentation. It will answer as well if a solution of sugar, mixed with yest, be exposed to the temperature of 80° throughout, so that the vinous fermentation shall proceed with rapidity. In this case the acetous fermentation goes on simultaneously with the vinous; but the former continues after the latter has ceased, and continues until very nearly the whole of the alcohol is acetified.

That it is the alcohol which is converted into vinegar, appears from the fact, that a very dilute mixture of alcohol and water, along with a little charcoal, will, in

about forty days, lose all traces of alcohol, and become vinegar.

Vinegar may be formed from solution of common sugar, sweet juices of fruits, especially the grape, infusion of malt, &c. By the distillation of wood it is obtained abundantly, along with tar, which can readily be removed. Cider, if long kept, changes into excellent vinegar; so also do weak wines and beers. In all cases, within certain limits, the greater the quantity of alcohol present, the stronger will be the vinegar, and the slower its formation. If the liquor be highly alcoholic, it will keep any length of time without souring.

The various kinds of vegetable matter existing in vinegar, although foreign to its constitution, render it apt to run into putrefaction by the process called *mothering*. This is prevented by distillation, and less perfectly by boiling; but flavour is in the former case lost. By freezing, it may be concentrated; for the ice is water, and may be removed. By saturating vinegar with lime or potash, evaporating to dryness, and distilling the dry salt with sulphuric acid, we obtain a perfectly pure acid in its most concentrated form. It is now colourless, transparent, exceedingly pungent in smell, and of a caustic acid taste. In this state it is called *acetic acid*: it does not differ from vinegar, but in purity and concentration. By a process of this kind, the tarry empyreumatic vinegar procured by distilling wood may be rendered as pure as that derived from any other source.

When acetic acid is highly concentrated, it is capable of crystallising. The liquid acid, at 60°, is of specific gravity 1·063. Even at this strength, there is some water present. If more water be gradually added, the specific gravity continually increases to 1·073. If more water be still added, the specific gravity, instead of increasing, diminishes continually. The vapour of the strongest acetic acid is combustible.

Theories have been brought forward to account for

the formation of vinegar during the acetous fermentation, founded on the belief that the absorption of oxygen from the atmosphere is indispensable: and the agency of the oxygen has been supposed to be the removal of carbon and hydrogen from the alcohol, by the formation of carbonic acid and water; for it is known that acetic acid contains less carbon and hydrogen than alcohol. A theory of this kind, however, has to contend with the fact, that although oxygen is absorbed during the acetous fermentation, and carbonic acid is formed, this absorption seems to be effected by some other carbonaceous matter present in the liquor, and not by the carbon of the alcohol; for vinegar may be formed perfectly, and with ease, even though the access of air be totally prevented. This fact is proved by many instances. Beecher included wine in a glass bottle, which it filled: he hermetically sealed the mouth, and exposed it to a digesting heat; after some time the wine was converted into very strong vinegar. (*Physica Subterranea*, Lipsiæ, p. 184.) Fourcroy and Vauquelin obtained vinegar from a solution of sugar contained in close vessels. Homberg included good wine in a bottle, and having closed it accurately, he fastened it to the sail of a windmill: in three days it was very good vinegar. It is a fact well known to every one, that a bottle filled with weak beer, and closely corked, will in some time be converted into vinegar. It may be said that air was absorbed through the cork: but this could scarcely happen: for, after a cubic inch or two of oxygen would thus be absorbed, the neck of the bottle would be filled with azote; and there being now no longer the aid of a partial vacuum, it is hard to conceive how air could enter. But the experiment of Beecher seems to me irrefragable; and, I think, we are bound to admit that the absorption of oxygen during the formation of vinegar is incidental, not necessary.

According to Gay-Lussac and Thenard, 100 parts of acetic acid consist of 50·224 carbon, 44·147 oxygen, and 5·629 hydrogen. If we alter these numbers very

little, their coincidence with the doctrine of volumes and correct specific gravities leads to a constitution of acetic acid, which seems to be the truth. Let us take 49·928 carbon, 44·508 oxygen, and 5·564 hydrogen, as the ratio in 100 parts of acetic acid, then the ratio in 38·1003 parts will be 19·023 carbon, 16·9576 oxygen, and 2·1197 hydrogen. Here the quantity of oxygen is the same as exists in 48·6807 parts of alcohol (see the scheme at page 337.), the quantity of carbon is 50 cubic inches less, and the quantity of hydrogen is 200 cubic inches less. The composition of acetic acid would stand thus:—

	Cub. in.		Grains.		Per cent.		According to Gay-Lussac and Thenard's analysis.
Carbon vapour	150	weighing	19·0230		49·928	or	50·224
Oxygen - -	50	- -	16·9576		44·508	or	44·147
Hydrogen -	100	- -	2·1197		5·564	or	5·629
	300		38·1003	or	100	or	100

The oxygen and hydrogen are here in the ratio which forms water, as was proved to be the case in acetic acid, some years since, by Dr. Prout. According to this view, when 48·6807 grains of alcohol are converted into 38·1003 of acetic acid, its oxygen remains unchanged: it parts with 50 cubic inches of carbon vapour, and 200 of hydrogen, which unite, and form the gelatinous cake always produced. This, when dried, becomes as thin as paper, and blazes at the candle, emitting a smell of scorched wood. Its composition may be similar to that of wood, the oxygen being derived from the air; or, when access of air is prevented, it may be a hydrocarburet. If alcohol be considered as a compound of water and olefiant gas, acetic acid will be a compound of water and carbon.

The following is a summary of the changes which probably happen when 95·278 grains of pure sugar are made to undergo both fermentations:—100 cubic inches of its carbon vapour combine with an equal volume of its oxygen, and form 46·5973 grains of carbonic acid, which

escapes. The remaining 200 cubic inches of its carbon vapour combine with the remaining 50 cubic inches of its oxygen, and 300 (the total quantity) of its hydrogen, producing 48·6807 grains of pure alcohol. Of the carbon vapour contained in this alcohol, 50 cubic inches combine with 200 of its hydrogen, probably constituting the gelatinous slime; while the remaining 150 cubic inches of carbon vapour combine with the remaining 100 of hydrogen and 50 (the whole) of the oxygen to form 38·1003 grains of acetic acid.

The acetous fermentation requires its peculiar ferment as well as the vinous. What its nature is, we do not know; but it is believed to resemble the vinous ferment, in being some modification of gluten. When a saccharine liquor ferments, the fermentation will proceed to the acetous stage, if the quantity of alcohol evolved be small, and the temperature be kept up. But although, in this case, the vinous ferment produced the acetous fermentation, the acetous ferment never produces the vinous fermentation. The slime found in the bottom of vinegar vats acts as a good acetous ferment.

Putrefactive fermentation.—The putrefactive fermentation affects both animal and vegetable matter. Animal matter consists chiefly of oxygen, hydrogen, carbon, and azote. During its putrefaction, hydrogen and azote combine and form ammonia; hydrogen also combines with oxygen, forming water, and with carbon, affording carburetted hydrogen: carbon and hydrogen also unite and form carbonic acid: the chief part of the carbon remains in some obscure state of combination for a series of years, if air be excluded; but if not, the carbon disappears after some time.

The smell of putrefying animal matter is in part attributable to phosphorus and sulphur, which exist in small quantity in it, and which dissolve in hydrogen during the new order of affinities. But beside the odour of these, there is some other far more disagreeable, the source of which is not known, but may depend

on the solution of animal matter in some of the gases evolved.

Putrefaction does not take place at low temperatures: hence the bodies of animals have been preserved for ages in ice, as fresh as at the day of their death. Moisture is so necessary, that animal matter, which has been dried by accident or design, will keep a great length of time. Of this, the catacombs of Palermo, where the dead bodies are preserved indefinitely long by the mere process of drying, afford a striking instance.

When vegetables putrefy, the changes are not so complex, because the elements concerned are fewer. The oxygen combines with hydrogen; another portion of hydrogen combines with carbon. The chief part of the carbon remains as such, unless free access of air be admitted, which then slowly combines with it.

During the putrefaction of animal and vegetable matter, much heat is produced; and if the mass be considerable, the heat continues a long time. I found the heat of a heap of stable manure 135°, and it maintained this temperature for a week; but it continued very warm for two months. Hay that has been stored damp often takes fire.

I once witnessed a singular case of putrefaction, which seems worthy of notice, as I do not remember to have seen any account of a similar case. It occurred at the Richmond Hospital school of medicine in Dublin, I think in 1828, and was seen by most of the lecturers and pupils. The body of a girl, about thirteen years of age, was laid on the dissecting table: there was nothing remarkable in its condition: it was summer. In some days a white smoke began to exhale, which increased for two days, and then became very dense. There was no more fetor at first than in ordinary cases; but at length a smell so intolerable arose, that it was necessary to remove the body to the vault. I occasionally watched it, but nothing further occurred; the smoke in a few days more ceased. There was no heat developed that I could perceive.

Ethers.—When equal weights of alcohol and sulphuric acid, both as strong as possible, are distilled, a liquor comes over, the chief ingredient of which is a light, odorous, colourless, highly volatile liquid, of a penetrating taste and smell. This is called *ether;* and as there are other ethers, it, for distinction, is called *sulphuric ether.*

According to the analysis of Dumas and Boullay, 100 grains of sulphuric ether consist of oxygen 21·24, hydrogen 13·85, and carbon 65·05. If we correct these numbers so as to make them correspond with the theory of volumes and the specific gravities of the gases which seem best supported, we shall have the analysis thus: —Oxygen 21·6616, hydrogen 13·5686, and carbon 64·7998 = 100. According to this corrected analysis of 100 grains, 39·1426 grains would consist of oxygen 8·4788, hydrogen 5·2998, and carbon 25·3640. Comparing this with the analysis of 48·6807 grains of alcohol, stated at page 337., it will appear that the quantity of carbon is the same in both.

	Alcohol. Grains.		Ether. Grains.	Difference. Grains
Oxygen	16·9576	-	8·4788	8·4788
Hydrogen	6·3591	-	5·2992	1·05985
Carbon	25·3640	-	25·3640	
	48·6807		29·1420	9·53865

The difference of composition between 48·6807 grains of alcohol and 29·1426 grains of ether exists only in the oxygen and hydrogen; and the quantity of these gases which constitute the difference are as 8 to 1, which is their ratio in water. Now, if we convert the above table of grains' weight into the volumes which they represent, it will stand thus: —

	Vapour of alcohol. Cub. in.	Vapour of ether. Cub. in.	Vapour of water. Cub. in.
Oxygen	50	25 and	25
Hydrogen	300	250 and	50
Carbon	200	200	
	550	475	75
condensed into	100	37·1	50

From which it is obvious, that if, from 100 cubic inches of the vapour of alcohol, we abstract the elements which constitute 50 cubic inches of watery vapour — that is, half of the total water in the alcohol — we shall obtain 37·1 cubic inches of the vapour of ether: for the ethereal vapour weighs 29·142 grains; and 100 cubic inches weigh 78·284 grains, as will hereafter appear.

It has been already shown, that alcohol may be considered as a combination of olefiant gas and vapour of water, in equal volumes, condensed to one half. In the above case, 200 cubic inches of carbon vapour are combined with 200 of the hydrogen, forming 100 of olefiant gas; and the remaining 100 of hydrogen are combined with the 50 of oxygen, forming 100 of watery vapour. In ether, 200 cubic inches of carbon vapour are combined with 200 of hydrogen, as in the case of alcohol: but the remaining 100 of hydrogen, and 50 of oxygen, which the alcohol contained, although in combination, are divided into equal parts; one half the volume of watery vapour only remaining in the ether, and the other half being eliminated as water. It therefore appears, that the change which alcohol suffers in becoming ether, is, in effect, the surrender of half the water which existed in a state of combination in it. Ether is alcohol minus half the water of the latter.

Whether this is the only difference, is a controverted question. It is generally believed, that in alcohol and

ether, the carburet of hydrogen is the same; and that it is olefiant gas which, as already shown, consists of two volumes of carbon vapour and two volumes of hydrogen, both condensed into one volume. Dr. Thomson maintains the opinion, that the basis is what he denominates tetarto-carbo-hydrogen, or what I have described in page 171. under the name duplocarburet of hydrogen, consisting of four volumes of carbon vapour, and four of hydrogen, both condensed into one. It is obvious that, in either case, the ratio of the elements is the same; and the only difference is the mode in which they are combined,—a subject on which we know almost nothing. Dr. Thomson cannot prove his opinion to be well founded, nor can any one else prove that it is incorrect. The fact that the hydrocarburet is evolved in the state of olefiant gas, when sulphuric acid acts on a small quantity of alcohol, does not seem favourable to Thomson's view, although it does not decide against it.

The theory of the formation of sulphuric ether is also a controverted subject. It had long been believed, as it is still by many, that when sulphuric acid and alcohol are distilled, ether is formed, because the affinity of sulphuric acid to water is such as to subvert the combination of the elements of the alcohol when aided by a high temperature, and to withdraw half its water, or the elements of water, in the manner already described. This view is supported by the fact, that an ether, which, according to Boullay, is absolutely the same as sulphuric, is obtained by the intervention of some other acids which have a powerful affinity for water, as arsenic and phosphoric; but it is opposed by the following considerations: —

When equal weights of alcohol and sulphuric acid are mixed, and no artificial heat applied, the result is not a mere mixture of these two liquids; for, although sulphuric acid forms insoluble salts with lead and baryta, the above mixture affords soluble salts with these bases. In fact, the olefiant gas of the alcohol acts the part of a base: it loses its gaseous state, combines with more than

half of the sulphuric acid; and the latter, in consequence of the union, loses half its saturating power. The combination of sulphuric acid with olefiant gas constitutes an acid different from all others; it is called *sulphovinic acid*. This, accordingly, is the chief ingredient when alcohol and sulphuric acid are mixed.

When sulphovinic acid is distilled, it is decomposed; the sulphuric acid reappears in its original state; and the other element, carburet of hydrogen, (which would be olefiant gas, were it in the gaseous state,) combines with water that had been present in the sulphovinic acid; and, according to the quantity of water with which the carburet of hydrogen combines, ether or alcohol will be formed. If there was much water in the sulphovinic acid, the result will be alcohol; if little, ether will be produced. This fact favours the idea that the hydrocarbon in alcohol and ether is the same.

It has been suggested by Mr. Hennell, the discoverer of the chief facts relative to the theory of the formation of sulphuric ether, that when equal weights of alcohol and sulphuric acid are distilled, the resulting ether may be not formed by the direct action of these two bodies, but indirectly by the previous formation of sulphovinic acid, and its continual decomposition, and recomposition from the residual unaltered quantities of alcohol and sulphuric acid. During the distillation, he tested portions of the liquid in the retort taken at different periods, with acetate of lead; and found that the quantity of insoluble sulphate of lead precipitated continually increased, because sulphuric acid was continually evolved by the decomposition of the sulphovinic acid. The reason that ether, and not alcohol, is generated during this distillation, is, that the quantity of water present, and not held by the sulphuric acid, is only sufficient to afford ether by union with the carburet of hydrogen evolved from its combination with sulphuric acid. But if, previously to the distillation, water had been added, then the result would not be ether, but alcohol.

At the commencement of the process for obtaining

ether, that liquid only is produced along with a trifling quantity of alcohol. When nearly the whole of the ether generated has passed over, *oil of wine* distils; this fluid, according to Mr. Hennell, consists of sulphuric acid, neutralised by carburet of hydrogen, and not in the least acid; it differs from sulphovinic acid only in containing twice as much carburet of hydrogen. Olefiant gas is disengaged about the same period. Then come water, sulphurous acid, and carbonic acid. The liquor in the retort blackens and thickens with evolved charcoal; and when cold, I have found masses of a solid black pitch in it, resembling common pitch.

A theory of etherisation must account for all these phenomena. In the subsequent stages, we must suppose that the alcohol which had diluted the sulphuric acid being now for the most part removed, the water which was abstracted from the alcohol having distilled over, and the sulphovinic acid all decomposed, the sulphuric acid is in so large a quantity, and so much concentrated, that it acts with greater energy than ever on a little alcohol remaining. The water is totally withdrawn from this alcohol; and it is hence resolved into carburet of hydrogen, part of which escapes as olefiant gas. The other part reacts on the sulphuric acid; sulphurous and carbonic acids and water result, and distil over. The pitch is the last remains of the carburet of hydrogen, which, no doubt, would have been eventually decomposed by the sulphuric acid. The reason that the sulphuric acid and the carburet of hydrogen, at the end of the process, do not form sulphovinic acid, as at the beginning, is, that the temperature has become considerably elevated.

When the vapour of ether is mixed with three times its volume of oxygen, and a burning body applied, it explodes with violence. A dangerous explosion occurred to me from the casual intermixture of common air in an apparatus in which ether had been distilled,—a candle having been applied to the tubulature. To consume the vapour of ether perfectly, 100 cubic inches

require 600 of oxygen; the results are, water, and 400 cubic inches of carbonic acid. It is obvious, that as oxygen does not change its bulk in becoming carbonic acid, and requires its own volume of carbon vapour, there must have been present 400 cubic inches of carbon vapour; and as the remaining 200 cubic inches of oxygen formed water, they must have met 400 of hydrogen. But the analysis already stated shows that water was originally present, the constituents of which amount to 50 cubic inches of oxygen, and 100 of hydrogen. Hence, ethereal vapour consists of 400 cubic inches of carbon vapour = 50·728 grains, 500 of hydrogen = 10·5985 grains, and 50 oxygen = 16·9576 grains; in all, 950 cubic inches, condensed into 100, weighing 72·2841 grains; and hence the specific gravity of ethereal vapour is 2·5407 by calculation. Gay-Lussac found it, by experiment, 2·586, and Despretz 2·5808.

Ether is a liquid of a penetrating taste and agreeable smell. Its specific gravity, when pure, is 0·7. It boils at 96°; but evaporates in the open air at all temperatures, and produces so great a cold, that water may readily be frozen by it. It is soluble in all proportions of alcohol, but only in a very large quantity of water. It dissolves $\frac{1}{12}$th of sulphur, and $\frac{1}{80}$th of phosphorus.

There are several other ethers known beside the sulphuric; but their nature is so far different, that they are combinations of the acid employed in their formation with other elements. Thus we have nitric ether, a compound of hyponitrous acid with the same elements as exist in sulphuric ether. Muriatic ether consists of muriatic acid, carbon, and hydrogen. Chloric ether contains chlorine, carbon, and hydrogen. Hydriodic ether is composed of iodine and olefiant gas. Acetic ether is a compound of acetic acid and the elements of sulphuric ether Oxalic ether is similarly constituted, but contains oxalic instead of acetic acid. There are a few others, but they possess no interest.

CHAP. III.

OF COMBUSTION.

One of the most remarkable, important, and least understood phenomena in nature, is the process of combustion. It has, unsuccessfully, occupied the attention of philosophers in all ages; and even at this moment, the chief difficulty remains unexplained. It would be in vain to detail the different theories which have been advanced, even in comparatively modern times, as they have not now a single advocate The theory which, of late years, has occupied most attention, is that of Lavoisier; the chief positions of which had been advanced in 1665, by the ingenious, or, as might be said, considering the period, the illustrious Dr. Robert Hooke. But, owing to circumstances, his opinions were forgotten; and, in all probability, were utterly unknown to Lavoisier. A very remarkable part of Hooke's doctrine on combustion is the following:—"This action, or dissolution (i. e. combustion) of inflammable bodies, is performed by a substance inherent in air, that is like, if not *the very same with, that which is found in saltpetre.*" Here is the foundation of the Lavoisierian theory, the combination of the combustible with oxygen. But Lavoisier had made the experiments, from which his theory was inferrible, long before any such theory was inferred; and we find him, in his *Opuscules Physiques et Chimiques*, 1773, utterly ignorant of the conclusions to which the experiments there described, and others not contained there, afterwards led him. According to Lavoisier, combustion can never take place but when oxygen is present. Oxygen gas is, according to Lavoisier, a compound of a gravitating base, caloric, and light. When a combustible substance is exposed to the necessary temperature in oxygen gas, the latter is decomposed, the gravitating basis of the gas combines with the combustible, and the heat and light

separate from the gas in the form of fire. Thus, the latent heat of the oxygen gas is the sensible heat which appears in the phenomenon: and he attributed to oxygen gas a greater quantity of latent heat than to any other. A different explanation of the source of the supply of heat was soon found necessary. It was supposed that the mean capacity of the oxygen and combustible, is greater than the capacity of the substance formed as the product of the combustion; and that the excess of the former heat should be evolved, and rendered sensible, as we find it to be. But modern researches do not correspond with these statements: it is found that the products of combustion have sometimes a greater capacity for heat, than the substances between which combustion took place. For instance, it was supposed that carbonic acid has a less capacity for heat than oxygen gas: hence, when charcoal is burnt in oxygen, the heat developed is chiefly the difference between the specific heats of the two gases. But it has been since affirmed, that carbonic acid gas has a greater capacity for heat than oxygen; and, if this be a fact, it ought to happen, according to the theory, that in the formation of carbonic acid, as there is no condensation, there should be an absorption of heat and production of cold, instead of a brilliant combustion. Nitric acid and nitre, in both of which the oxygen has lost all the heat that belonged to it as a gas, are capable of affording combustions with combustible bodies, the heat resulting from which is much more considerable than oxygen, in the solid state, ought to give out, consistently with the doctrine of capacity. If, with Robins, we suppose that a cubic inch of gunpowder, when exploded in a vacuum, produces 244 cubic inches of gas, the enormous quantity of heat necessary to supply the increased capacity of the particles, now become gaseous, cannot possibly, according to this doctrine, be derived from solid oxygen, which, were it even in the gaseous state, would contain less specific heat. In such cases, recourse must be had to latent heat.

Another defect that was soon observed in the theory

of Lavoisier, related to the emission of light in combustion. The quantity and quality of the light evolved, was found to depend on the nature of the combustible: and it frequently occurs, that light in abundance appears in combinations, when oxygen is not present. A modified theory was then proposed:—Oxygen *gas* consists of oxygen (as the gravitating base was called) combined with caloric. Combustibles consist of an unknown base, combined with light. In combustion, a double decomposition takes place: the oxygen gas gives up its heat, and the combustible its light; the heat and light combine, and form fire; while the oxygen and combustible base form the new product. This theory is, of course, liable to the same objections with regard to the source of the heat.

The difficulty arises, in part, out of the opinion, that heat and light are material agents. But did circumstances permit our understanding heat as a mere condition of matter, which, in my opinion, they do not, one source of difficulty would be removed. It appears to me, that, admitting the materiality of heat, we should not singly look for its source, during combustion, in changes of capacity, or in the quantity which bodies contain in a latent form, in consequence of their being liquid or gaseous. We do not know sufficient on the subject of the quantity of heat rendered latent in changes of state, or the alteration of quantity that arises out of change of capacity, to render such a restriction, as to the source of what is developed in combustion, safe in such investigations. When phosphorus, charcoal, sulphur, or a metal, burns in oxygen or chlorine, or when gunpowder burns in a vacuum, much heat is evolved. This must certainly proceed from the solid or the gas, or, most probably, from both. We have not any knowledge of the real zero of temperature; but it seems certain that the absolute quantity of heat contained in matter must account for that developed in combustion. Until something more precise is known of the quantities of heat which constitute the latent caloric

of different states of existence in matter, or the specific quantities which different kinds of matter require, it seems but prudent to refer the heat of combustion to the general stock which all matter contains, without studying the circumstances by which such heat is restricted, in its recondite residence, as to solidity, liquidity, or gaseous form.

These are not the only difficulties that beset the Lavoisierean theory of combustion. Its fundamental position is, that combustion never takes place but when oxygen is some way or other present. At its first promulgation, combustion was identical with oxidation: but the English chemists made the essential difference to consist in the simultaneous development of heat and light with the occurrence of oxidation. Indeed, the subject has been needlessly perplexed by a want of agreement as to the meaning of the term combustion; or, in other words, what class of phenomena should be considered as constituting it. It is singular that, in almost all chemical works of the day, oxidation, the main feature of the French theory, and the insurmountable obstacle to the disposal of the question, is still retained. What is the use of such a restriction? It unnecessarily complicates the difficulty, by excluding a numerous and important class of phenomena, in which heat and light are concerned without oxygen. Why should we not take the word combustion in its obvious and popular acceptation, — that meaning under which it was originally adopted in physics? We say, the fire burns, a gas-light burns; and we merely mean that intense light and heat are emitted from a body affected by some condition which we do not further trouble ourselves about. The view taken by sir H. Davy seems to me by far the most consonant to phenomena, and to divest the subject of those difficulties which a useless restriction has imposed upon appearances quite difficult enough in themselves to comprehend. Generalisation is the great instrument of research, as well as of memory; and the greater number of facts a generalisation contains, the

more important an instrument it becomes. Sir H. Davy's view is simply an expression of facts; and it seems to comprise all the ingredients of an adequate definition.

The restricted sense of combustion was founded on the admission, that nothing could burn unless oxygen were present. The progress of discovery has developed so many exceptions to the theory, that they show equal the number of the conforming instances. If a metal is burnt in oxygen, the case is avowedly one of combustion: but if the same metal is burnt in chlorine, with just the same appearances, it is not combustion; it is then designated by the timid name *deflagration*. If potassium be heated in oxygen, it is admitted that combustion takes place: but if potassium be heated in cyanogen gas, the metal burns with the same splendour, yet this is not combustion. Iron wire undergoes a brilliant combustion in oxygen: iron heated in sulphur burns with all the appearances of brilliant red fire. Why should not this be a case of combustion equally? The metal thorinum, when heated in gaseous sulphur, burns just as well as in gaseous oxygen. Should not both phenomena be equally entitled to be considered as combustions? When gunpowder is heated, it explodes with considerable emission of heat and light: there is another powder, iodide of azote, which, when touched or heated, explodes violently, and evolves intense heat and light: one is called combustion, the other is not. A mixture of oxygen and hydrogen, when heated, explodes with the production of heat and light. If that gaseous compound of oxygen and chlorine, called euchlorine, be heated, it explodes with the sensible phenomena of fire also: the circumstance that the former is a case of combination, and the latter of decomposition, affords no grounds for denying that both are cases of combustion. Chloride of azote, if heated, explodes violently: peroxide of hydrogen, if dropped on oxide of silver, explodes: anhydrous liquid hydrofluoric acid, if brought in contact with potassium, explodes: and gaseous bihydroguret of phosphorus, if subjected to diminished pressure, explodes with violence.

In all these instances, and many more, in which detonation happens, the phenomena of fire appear; yet they are not admitted as cases of combustion.

The flame, which frequently accompanies combustion, consists of heat and light; the latter being sometimes incommensurate with the former: thus, the flame of hydrogen, when perfectly pure, emits scarcely any light; while good oil gas, which produces much less heat, affords a dazzling illumination. According to sir H. Davy, "flame is gaseous matter, heated so highly as to be luminous, and that to a degree of temperature beyond the white heat of solid bodies; as is shown by the circumstance, that air not luminous will communicate this degree of heat. This last is proved by the simple experiment of holding a fine wire of platinum, about the $\frac{1}{20}$th of an inch from the exterior of the middle of the flame of a spirit lamp, and concealing the flame by an opaque body; the wire will become white hot, in a space where there is no visible light." — "Whenever a flame is remarkably brilliant and dense, it may always be concluded, that some solid matter is produced in it: on the contrary, when a flame is extremely feeble and transparent, it may be inferred that no solid matter is formed." — "The density of a common flame (that of a gas light or candle) is proportional to the quantity of solid charcoal first deposited, and afterwards burnt." — "But to produce this deposition from gaseous substances demands a higher temperature." — "By inflaming a stream of coal gas, and passing a piece of wire gauze gradually from the summit of the flame to the orifice of the pipe, it was found that the apex of the flame, intercepted by the wire gauze, afforded no solid charcoal; but, in passing it downwards, solid charcoal was given off in considerable quantities, and prevented from burning by the cooling agency of the wire gauze; and at the bottom of the flame, where the gas burnt blue in its immediate contact with the atmosphere, charcoal ceased to be deposited." *

* Davy on the Safety Lamp, &c. 91. 54. 87. 51.

From these statements, it does not very clearly appear how "solid matter is produced" in a brilliant dense flame, and how solid charcoal is to be understood as "first deposited, and afterwards burnt," in a common flame. When a stream of coal gas is set on fire, the experiment of collecting carbon on a piece of wire gauze held in the flame, seems to prove that the gas is decomposed. But one would be inclined to imagine that the resulting carbon would separate in vapour; and that its appearance in the solid state on the wire gauze happened merely on account of the casual condensation; the temperature of the wire being infinitely beneath that of the flame, as shown in the first experiment quoted, and also beneath that at which carbon could remain a vapour. It does not appear easy to comprehend in what manner carbon, emerging from the gaseous state in carburetted hydrogen, and instantly passing into a new gaseous state by combining with oxygen, could have been deposited in the solid state in the flame; or how its existence in the flame *as a solid* could render the flame in a high degree luminous. Not only does it seem that no appreciable time intervenes, but that there is no conceivable interval between the moment when the carbon is admitted to be a vapour, and its metamorphosis into another state of vapour (carbonic acid) during combustion. It seems to me, that the only inference we can draw is, that the presence of gaseous carbon in hydrogen causes the latter to burn with a white light in some manner unknown: and this amounts to nothing beyond a statement of a fact.

I conceive that there is something else in operation besides the deposition of solid matter, in flame, which causes the evolution of a dense light. On this subject I made several experiments some time since: they are yet imperfect. The following is an abstract of a few of them: — A solid, unchangeable body, when heated to a certain degree, becomes luminous; and the hotter it becomes, the more intense is the light which it emits. There is no reason to believe that flame, whatever its

nature may be, is not capable of existing at different temperatures. Consistently with the analogy of other matter, we may suppose that, at high heats, it is more luminous than at lower. This supposition accords with, and is borne out by, facts. If a single jet of coal gas, from a tube of very small bore, be kindled, it burns with a flame which, except at the bottom, is brilliantly white. To try the effect of lowering the temperature of this flame, I made a hollow cylinder of ice by means not necessary here to describe, the diameter of which was about half an inch. By inclosing the jet in this, so that the flame was in the axis of the cylinder, like a lantern, the flame instantly became blue, and showed almost no light: it at length went out. The same effect, but less perfectly, was produced by bringing two pieces of ice in contact with the flame, one at each side, and very close to each other: and sponges dipped in ice water answered nearly the same end. Even by blowing one's breath on a jet of flame, it may be made to burn blue. Every one has observed that the bottom part of a common gas light is blue and illuminous; and this fact has been the subject of much speculation. I once thought that the carbonic oxide which exists in gas was burnt here; but the foregoing experiment gives us the true solution of the blue colour of that part of the flame. It is partly cooled by the proximity of the brass, but chiefly by the constant current of cold gas ascending from the holes of the burner; these causes acting in the same manner as the ice. To prove that the blue part is not so hot as the white portion, a very simple experiment will suffice. If a bit of paper, rolled up as a match, be run upwards through the axis of an Argand gas burner from the underneath crutch, so that the top of the paper shall stand in the axis of the hollow cylinder of blue flame, it will remain unaltered; but if the paper be pushed up towards where the flame begins to whiten, it will instantly take fire. The best circumstances for the experiment are, that the flame, included in a glass chimney, shall be short and cylin-

drical throughout, not coalescing at the top; and the paper should be viewed by looking down through the axis of the flame. Another proof that the current of gas, from the holes in the burner, cools the flame, is, that if a wire heated red in the flame be passed into the current near the burner, it is instantly obscured by cooling.

"If the cooling of the flame were really the cause of its blueness and deficiency of light, I thought, that by removing the cause of its cooling, the blue might be changed into white, like the rest of the flame. I therefore tied a bladder filled with coal gas to a long tobacco pipe, the bowl being removed. On pressing the bladder, and inflaming the gas, it gave off a long stream of flame, of which more than an inch was blue, and the rest white. "About three inches of the end of the pipe were now heated to whiteness, and maintained at this degree; the bladder being pressed, the flame burnt white throughout, except about one eighth of an inch, which was somewhat bluish. For this experiment a red heat will not answer. A non-explosive mixture of common air and coal gas, passed through an Argand burner, afforded a blue flame without any white light; for the dilution of the inflammable gas by an incombustible one prevented the flame from reaching the temperature necessary to its becoming fully luminous. I caused a massive Argand burner, three inches in diameter, with thirty capillary holes, to be made: and having passed good coal gas through it, and kindled the gas, I found that the flame was almost totally blue, and showed scarcely any light: the great quantity of brass, and the cold current, were adequate to deprive the capillary jets of flame of the quantity of heat required for the production of white light. If a red-hot iron be introduced into the blue part of a gas flame, the latter instantly becomes white; but if the iron be cold, it has no effect. The flame of a taper, held very close to the blue flame, renders it whitish; but the flame of burning sulphur applied, has not this effect, as it is not sufficiently hot for the purpose.

Although the blue part of the flame is colder than the white, a thread of glass grows apparently of a brighter red heat when held in the former; because the whiteness, brilliancy, and semi-opacity of the white flame, conceal the heat to which the glass is raised in it: but this is not the case in the blue flame; for it, being but little luminous, and very transparent, affords a contrast with the redness of the glass.

A candle has scarcely any blue light, because the carbonised wick is the worst of all conductors of heat. But a long wick cools the flame by radiation, and there is a diminution of light, although the flame does not become blue.

A common jet flame of gas is surrounded on all sides by blue flame; for it is every where in contact with the cold atmosphere. The eye does not perceive this universal blue margin, being dazzled with the white light, unless a piece of thick card, or some opaque body, cut precisely to the shape and size of the white part of the flame, be interposed between it and one eye—the other being kept shut. Then the card appears surrounded by a margin of blue flame.

Carbonic oxide burns with a feeble blue flame, which shows very little light: the temperature of this flame is also very low. In order to discover if the low temperature was the cause of its deficiency of light, I filled an iron bottle with a mixture of iron filings and whiting, both perfectly well dried. The mouth of the bottle was stopped with an iron plug; and in the side of the bottle was drilled a hole. The bottle, being placed in a furnace, was heated as high as it would bear without melting. On drawing it out of the furnace, there was a long jet of flame issuing from the hole, which was almost white.

I found that the flames of sulphuretted hydrogen, and even common hydrogen, issuing out of a tobacco pipe heated to whiteness at the end, were by no means so blue and pale as under ordinary circumstances: they showed, also, more light. During such experiments, the

tobacco pipe must not be white-hot at the beginning merely, but must be sustained so throughout.

From these, and many other experiments, I infer that, although the temperature of flame is not the only cause of its light, but it is connected with it, and aids some other cause unknown. Were the light in proportion to the temperature, the flame of hydrogen should be more luminous than that of coal gas.

The light and heat of combustion have been attempted to be explained by the agency of electricity. It has been supposed that different kinds of matter exist, naturally, either in the positive or negative state of electricity; that when two bodies thus circumstanced combine, the two states of electricity annihilate each other, and produce a modified spark, which is the cause of the heat and light. I have so fully expressed my opinions on this subject, and have detailed such a number of opposing experiments and considerations elsewhere *, that, in this place, I content myself by stating my belief that the electro-chemical hypothesis is utterly incompatible with all known phenomena.

In conclusion, then, it is perhaps the safest, because the most comprehensive, idea for the student to entertain of combustion, that it is the emission of light and heat from bodies in the act, generally, of combining, but sometimes of separating: that the heat is part of the combined or latent caloric of the combining bodies: that the light may also proceed from them; although it seems chiefly dependent on one of them — the combustible.

* See Essay on the Origin, Progress, and present State of Galvanism

CHAP. IV.

ON THE ULTIMATE PARTICLES OF MATTER.—THEIR RELATIVE WEIGHTS.— THE RATIOS IN WHICH THEY COMBINE. — NATURE OF ATOMIC NUMBERS.

THE question, whether matter is infinitely divisible, or consists of atoms *, has been agitated for more than 3000 years: yet it is still a disputed point; and our opinions on this subject, whatever they may be, are hypothetical. Unless finite divisibility be admitted, the most important series of phenomena in chemistry will be left in the situation of ultimate facts incapable of further explanation. Yet the phenomena ascend one degree in the scale of cause and effect; and are inferable *à priori*, if the existence of indivisible particles be supposed. Such particles may, for shortness, be called *atoms*: if matter be infinitely divisible, there can be no such thing as an atom; for the word imports that which cannot be divided.

It would be a waste of space to enter into the opinions, or arguments made use of by the ancient poilosophers, on each side of this question, some of which, if not convincing, were at least plausible. Of this kind was the curt dogma of Diogenes Laertius,—"In a finite body, there cannot be an infinite number of parts." The peripatetics affirmed, that matter is infinitely divisible; and the notion was adopted by the Cartesian school. The Epicureans, on the contrary, contended that matter is composed of atoms, indivisible, hard, and impenetrable. Lucretius, the powerful advocate and able expositor of this system, in his well known and beautiful poem, says,

> Sed quæ sunt rerum primordia nulla potest vis
> Stringere, nam solido vincunt ea corpore demum.

These atoms constituted the ὕλη, or first matter, of which all things are composed, and concerning which so much controversy and incomprehensible notions are to

* From ἄτομος, indivisible.

be found amongst the ancients. In later times, it was the fashion to bring forward arithmetical and geometrical demonstrations, to prove that matter may be divided infinitely; but these fail in their object, inasmuch as they only prove the infinite divisibility of the magnitude of matter, and are by no means applicable to matter itself. It is certainly true, that any magnitude, however small, might be reduced to one half; that this half might still further be divided; and so on for ever, without its being reduced to nothing. Indeed, we cannot consider magnitude independently of the idea of divisibility without limits; but it should not be admitted as an inference, that matter permits infinite division, because the space which it occupies may be conceived to be the subject of an infinite division. It is possible to conceive the division of a grain of sand into a million parts, and each of these parts into a million other parts, and so on. And if at length the parts can no longer be conceived to be divided, it can only be so because they are annihilated, which, so far as human means are concerned, is impossible. But, in point of fact, it may be true that a grain of sand cannot be divided into more than a thousand or ten thousand parts; that each part then becomes what we call an atom, or ultimate particle of matter, invisible to our best microscopes, and of such cohesion as to resist all the energies of nature tending to a further division. In fine, it seems to me, that much of the controversy which so long agitated the philosophers of former times, with regard to the infinite divisibility of matter, and which at present ought to be a subject of greater interest than ever, originated in the want of agreement on the nature of the question: one side insisting on the infinite divisibility of including space; and the other side insisting on the possibility of a limit to the divisibility of the included matter, which, although it may be *conceived* to be surpassed, is not in the operations of nature. Partly in each of these senses might be understood the apparently paradoxical aphorism of Zeno, that although

a body is infinitely divisible, it does not consist of infinite parts; and if he meant that the magnitude of a body may be indefinitely divided, although the number of its ultimate divisions is limited, I apprehend the chemists of the present day would not dissent.

The opinions of sir Isaac Newton concerning the atomic constitution of matter, were nearly the same with those attributed to Moschus, who lived 3000 years before him, except that the former rejected the atheistical notion of the eternity of atoms. He says, "It seems to me that God in the beginning formed matter in solid, massy, hard, impenetrable, moveable particles; and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces, no ordinary power being able to divide what God himself made one in the first creation."

In all compound substances, formed by nature or art, the compound ingredients are found to exist always in the same relative quantities. A piece of marble always contains the same relative quantities of carbonic acid and lime, no matter from what part of the world the specimen was derived. Water consists of the same proportions of oxygen and hydrogen, whether it falls from the atmosphere, or is taken from the subterraneous spring, or from the ice of the north or south pole. Salt is composed of the same proportions of chlorine and sodium, whether obtained from mines, lakes, or the ocean. If mercury be exposed to heat in oxygen gas, the metal will continually absorb the oxygen up to a certain point, and then, be the excess of oxygen ever so great, not a particle more will the metal receive; for a permanent and saturated compound is now formed, the constitution of which will be the same, whether the experiment was made in Europe or America. From such phenomena as these, we derive the important law that matter does not chemically combine with matter in all proportions, but only in one invariable relative quantity for each compound; and the law holds equally,

whether the number of different kinds of matter combining be two or more.

There are cases which do not seem reducible under this law, and which appear to constitute a class of combinations in which the substances concerned unite in all proportions. Alcohol or sulphuric acid, to all appearance, unite chemically with any quantity of water; and many instances of the same kind might be adduced. But these unlimited combinations may be so only apparently; we may conceive them referrible to the general law in the following manner: -- Sulphuric acid may combine with a determinate and invariable quantity of water to form a hydrate; this hydrate being a new substance, may combine with a new determinate quantity of water; and this new compound again with another, and so on: and all these compounds may unite with each other, so as to afford every conceivable ratio of the ingredients, or apparently to dispense with all limits to combination. Either view may be sustained; but it is remarkable, that, when the existence of determinate ratios is indistinct, it always happens that the affinity is weak and indecisive, and the changes of properties consequent on combination are inconsiderable.

If we admit the existence of atoms, *i. e.* particles which can be no further divided; and also the position, that matter can combine with a different kind of matter only in a certain invariable ratio; some very important corollaries may be deduced: one of these would be, that when two kinds of matter combine to form a compound, the two kinds combine atom to atom. For in order to combine chemically, the two bodies must be reduced to their ultimate division; and then an atom of one kind must, to form the compound in question, always combine with an atom of the other: it cannot combine with half an atom, for, according to the hypothesis, no such thing exists; and it cannot combine with two atoms, because it is saturated with one*, that is, its attraction is satisfied by one atom, and

* Cases which do not fall under this condition will afterwards be considered.

is no further exerted. Hence the resulting compound consists of an atom of each kind of matter; and it is to be considered as still *one* atom, although consisting of two: for, were the two atoms separated, the compound would cease to exist as such; and the compound atom cannot be divided so that its halves shall still be compound; for the individual atoms, according to the hypothesis, cannot be divided. There is, therefore, a great difference between a simple and a compound atom: the former cannot be divided; the latter can, but then it is decomposed and resolved into two simple atoms.

In this way, the immutability and constancy of the relative quantity of the ingredients composing any body become intelligible. If, in a grain weight of any kind of matter, there be, as the hypothesis supposes, a certain number of atoms, say a thousand, each being indivisible; and if, in a grain weight of some other kind of matter, there be an equal number of atoms; and if the two grains of matter enter into combination; it is quite obvious that the resulting compound will not only be homogeneous, *i. e.* of the same nature throughout, but that in all other cases of its formation, the same compound exactly will be produced. It will be homogeneous, because each atom of one kind must have combined with one atom of the other: less than an atom cannot have combined, because atoms are indivisible; more than an atom cannot have combined, because the affinity is satisfied by one, and there is no attraction to another. Hence, each compound atom will consist of $\frac{1}{1000}$th of a grain of one kind of matter, and the same quantity of the other; and there will be but 1000 atoms of the compound. But if there had been a grain (= 1000 atoms) of one kind, and two grains (= 2000 atoms) of the other, the very same mode of combination would result; with this difference, that the excess of the latter (viz. one grain, or 1000 atoms,) would remain uncombined, and merely mixed with the compound produced.

But if it be denied that matter consists of atoms, and if it be asserted that it is infinitely divisible, it becomes difficult to comprehend why any constancy should be observable in compounds. For instance, in the case just supposed, in which an atom is equivalent to $\frac{1}{1000}$th of a grain, if the equivalent of an atom of one kind of matter may combine with less than the equivalent of an atom of the other, there is nothing to prevent its combining with half, a hundredth, a millionth part of an equivalent; an infinite number of combinations would be producible: and it is hard to conceive how compounds, constant as we find them in their composition, could be produced, or how such a state as saturation could occur, unless as a matter of chance. If a grain of A may combine with *any* quantity of B, there must be as many possible compounds of A and B as there are possible quantities of A and B, or they must be infinite; and we know that this is not the fact. But the case is very much altered, if we suppose that there is but one elementary quantity of A and B, viz. the atom of each, and that all other quantities are multiplications of it; for then there can exist but one possible combination, consisting of an atom of each; the affinity being in that case satisfied, and no further attraction exerted.

Hitherto, for the sake of simplicity, it has been taken for granted that different kinds of matter combine only in the quantity of a single atom of one to a single atom of another, admitting that matter is finitely divisible. The case is in reality very different; we know that two, three, or more atoms of one kind may combine with one atom of another, and that in each case compounds of distinct natures result. Cases of this kind receive as ready an explanation, as those in which a single atom combines with a single atom. We may understand combinations of this kind in two ways. Suppose an atom of A to combine with an atom of B, and a compound to be formed possessed of certain properties. The affinity of A for B may remain so

far unsatisfied, that an attraction to another atom of B may exist; a second atom will accordingly be taken into the combination when opportunity permits, and a compound will be formed with properties essentially different from those of the former. The same may happen with a third atom of B, and a third compound may be produced. Or an atom of A being combined with one of B, that combination may, *in its capacity of a compound*, exert an affinity for an atom of B, and may combine with it so as to form a compound consisting of one atom of A and two of B. This last combination may in the same manner take up a new atom of B, and so on.

Be the mode of combination what it may, it is certain that a substance, A, may combine with such a quantity of another substance, B, as will form a definite compound; yet another definite compound, quite different from the former may be produced, if a second quantity of B can be made to combine with the compound already formed; and in like manner a number of successive quantities of B may produce distinct compounds, the number of which, however, rarely exceeds three. In all such instances (with a very few exceptions), it is found that the successive quantities of B, which are added, are equal to each other. That this ought to happen, clearly appears from what has been already explained of the atomic constitution of matter. For the illustration of this subject, let us first consider the combination of zinc with oxygen. There is but one such known; to form it, 100 grains of zinc combine with 23·53 of oxygen; the affinity of the two elements is then satisfied, and no further attraction seems to exist. But if another quantity of oxygen could be absorbed by the zinc, to form a second oxide, it would be at least 47·06 grains, or as much more as the first quantity. In the instance of mercury and oxygen, experiment proves that, in round numbers, 100 grains of the former combine with four of the latter to form the protoxide. Now, why did 100 grains of

mercury combine with four of oxygen? The answer supplied by the supposition of the atomic constitution of matter is, that there are as many atoms of mercury, in 100 grains' weight of it, as there are atoms in four grains of oxygen, notwithstanding the difference in their appearance and constitution; hence the two substances combine atom to atom, and afford a compound constant in its characters and composition. It, however, by no means follows, that each atom of mercury has no further affinity for oxygen. On the contrary, experiment proves that it has, and that it will unite with an additional quantity. But what is the amount of the additional quantity? If, to form the protoxide, each atom of mercury attracted one atom of oxygen, it is obvious that, if a further attraction takes place, each atom of mercury must attract an additional atom, at least, of oxygen; for there cannot exist less than an atom; that is, two atoms of oxygen will be now combined with one of mercury. The 100 grains of mercury, originally combined with 4 grains of oxygen, will now be united with 8. But 8 is the double of 4; the new oxide, therefore, contains twice as much oxygen as the protoxide: and were there a third oxide, it would contain at least three times the quantity of oxygen existing in the first, and so on. Molybdenum combines with oxygen in three doses*, forming three distinct oxides: the first oxide consists of 1 atom of metal and 1 of oxygen; the second of 1 + 2; and the third of 1 + 3. Potash combines with two doses of tartaric acid; one being twice as much as the other. A vast number of instances might be adduced.

* There is not, perhaps, a word in the language that conveniently expresses the quantity of a body which enters into combination. *Atom* is not only hypothetical, but often inapplicable, as when half atoms occur. *Equivalent* is only expressive when comparison with a correlative equivalent is directly implied. *Proportion* means similitude of ratios. *Proportional* is one of the terms of a proportion. *Combining quantity* or *weight* is sometimes expressive; but beside being unwieldy, it is not always applicable. *Dose* (from διδοται, of διδωμι, I give,) is universally employed to designate a *determinate* or *definite quantity* of a thing *given*. Thus, in the sense above meant, a dose of oxygen would mean a determinate quantity of oxygen given to some other body. It has the quality of involving nothing beyond a fact, and can often be used with advantage.

In all cases, it is a matter of indifference which of the combining substances we assume as the constant quantity; thus, 100 grains of A unite with 50 of B, or twice as much (100), or thrice as much (150). Or the same thing may be expressed by saying, that 100 grains of B unite with 200 grains of A, or half as much (100), or one third as much (66·666): the multiple ratio does not affect one kind of matter otherwise than another.

In the case of mercury and oxygen just now adduced, it was said that 100 grains of the former will combine with 4 or 8 of the latter. It may be asked, what, then, will be the consequence, if 100 grains of mercury and an intermediate quantity of oxygen — 6 grains, for instance — are presented to each other under proper circumstances for combination? will no union take place, because the ratio of oxygen to the metal is neither 4 nor 8? or will 4 of oxygen combine, and the remaining 2 be rejected? Under such circumstances the case would be as follows:—100 grains of mercury will unite with four of oxygen; the protoxide will thus be formed. There are now 2 grains of oxygen to be disposed of; they will unite with as much of the protoxide as contains 50 grains of mercury. These 50 grains were previously combined with 2 grains of oxygen; they are now combined with two more, four in all; hence the 50 grains are converted into peroxide. Thus we should have a mixture of 52 grains of protoxide and 54 of peroxide.

Even gases enter into combination with each other with the same peculiarity. Thus, when azote and oxygen unite to form the protoxide of azote, they always do so in the ratio of 60·071 grains of azote to 33·915 of oxygen. To form the deutoxide, the same quantity of azote will require 67·83 grains of oxygen, or twice the original quantity: for hyponitrous acid, the azote will require thrice as much oxygen, or 101·746 grains: for nitrous acid, the azote takes four times as much oxygen, or 135·66 grains: and, for nitric acid, the oxygen must be five times greater, or 169·576 grains. Thus, the doses

of oxygen that combine with any quantity of azote, to form the foregoing substances, will be to each other as the numbers 1, 2, 3, 4, 5; and never $1\frac{1}{2}$, $2\frac{99}{100}$, $3\frac{1}{1000}$, &c.; nor any other assignable fractions, however near they may be conceived to approach the whole numbers bearing the above relation.

The researches of chemists have proved that this mode of combination, *per saltum*, takes place in almost all the cases of decided chemical union which have been made the subject of accurate observation; and so much so, that the phenomena have been generalised into a law. The law is thus expressed by Berzelius: — "When a body, A, combines with a body, B, in several proportions, the numbers expressing these proportions are integer multiples of the smallest quantity of B that A can absorb." The import of this law cannot be mistaken. In the case of oxygen and azote, the smallest quantity of the former that combines with 100 grains of the latter, is 56·458 grains. As they form a second compound, the quantity of oxygen which constitutes the second dose, is an integer multiple of the first (that is, the first multiplied by a whole number), or twice 56·458 =112·916. In the third, the oxygen is thrice as much, or 169·374: in the fourth, the oxygen is four-fold, or 225·832: and, in the fifth, it is five-fold, or 282·29. Thus, the smallest dose of oxygen is multiplied by the whole numbers, 2, 3, 4, 5, to give the successive compounds: or the law may be otherwise expressed, by saying, that the smallest dose of a combining body is an aliquot part, or submultiple, of all the others. Another expression of it, which requires explanation, is to be found in books to the following effect: — "When two bodies combine in several proportions, the first proportion is either a multiple or submultiple * of all the rest." The mode of expression renders this difficult to understand; perhaps the following will be more readily comprehended: — "When two bodies combine in more than one ratio, the quantities constituting the first ratio are

* A divisor without a remainder.

in the relation of multiple and submultiple to the quantities which constitute all the other ratios." The instance of azote and oxygen will illustrate this: their combinations may be represented in two ways; either gas being made the constant quantity, and both being expressed in weight: —

Azote.		Oxygen.		Doses of oxygen.		Oxygen		Azote.		Doses of oxygen.
100	+	56·458	=	1		56·458	+	100	=	1
100	+	112·916	=	2		56·458	+	50	=	2
100	+	169·374	=	3	or, what is the same.	56·458	+	33·333	=	3
100	+	225·832	=	4		56·458	+	25	=	4
100	+	282·290	=	5		56·458	+	20	=	5

In the first arrangement, the first dose of oxygen, 56·458, is a submultiple of all the rest: in the second arrangement, the first dose of azote, 100, is a multiple of all the rest: so that the terms, multiple and submultiple, refer to the two different bodies, and resolve the law into the same meaning as the other expressions of it.

But although, in the combinations of azote with oxygen, the doses of the latter are represented by the numbers 1, 2, 3, 4, 5, it does not follow that a regular arithmetical progression is always to be expected, either when weights or volumes are concerned. All that the law of multiple ratio, as it is commonly called, declares, is, that the doses shall all be multiples of the smallest: and no common difference between the terms of the progression may be discoverable. Thus, in the combination of chlorine with oxygen, the doses of the latter, by weight or volume, which combine with a given weight or volume of the former, are as 1, 4, 5, 7. Perhaps compounds containing oxygen to the amount of 2, 3, 6, may be hereafter discovered: or, perhaps, such may be the nature of the affinity, that these compounds do not exist.

There is a circumstance attending these, and all other gaseous combinations, which it is of great importance to notice. It has been said above, that be the quantities of azote and oxygen, which enter into combination, what they may, the *ratio* of these quantities will always, when

protoxide is formed, be 60·071 of azote to 33·915 of oxygen; and this ratio may be so expressed, or in its lowest terms, viz. 1·771 of azote to 1 of oxygen; or in any other numbers, provided that the relation be preserved. The reason for selecting 60·071 grains, and 33·915 grains, is, that the former is the weight of 200 cubic inches of azote, and the latter is the weight of 100 cubic inches of oxygen. Two to one, then, is the ratio in which these gases combine, by volume, to form the protoxide of azote. Now, as the weight of oxygen is doubled to form the deutoxide, tripled to form hyponitrous acid, quadrupled to form nitrous acid, and quintupled to form nitric acid, the same multiplication must happen when cubic inches, or volumes of any kind, are concerned: and we shall, consequently, observe the same ratio subsisting between the volumes, as between the grains' weight. The following table will show the relation in both ways: —

	Cubic inches.			Grains' weight			Ratio of oxygen by weight or volume.
	Azote.	Oxygen.		Azote.		Oxygen.	
Protoxide of azote	200 +	100	or	60·071	+	33·915	1
Deutoxide - -	200 +	200	or	60·071	+	67·8306	2
Hyponitrous acid	200 +	300	or	60·071	+	101·7459	3
Nitrous acid - -	200 +	400	or	60·071	+	135·6612	4
Nitric acid - -	200 +	500	or	60·071	+	169·5765	5

And it is obvious, that, either by weight or volume, the relation of the quantity of oxygen in all the compounds is as 1, 2, 3, 4, 5, the quantity of azote being always the same. The same relation is manifest in all gaseous compounds, the composition of which is well ascertained; and the facts have been generalised into a law, called the *law of volumes*, which has been thus expressed by Gay-Lussac, its discoverer: — "All gases which act on each other, always combine in the most simple ratios; the ratio being as 1 to 1, 1 to 2, or 1 to 3." * Thus, 1 volume of oxygen requires exactly 1 volume of hydrogen, to form deutoxide; and 2 volumes of hydrogen, to form water: 1 volume of hydrogen re-

* Mémoires d'Arcueil, ii. 218.

quires 3 of azote, to form ammoniacal gas: 1 volume of hydrogen requires 1 of chlorine, to form muriatic acid gas: 1 volume of muriatic acid gas requires 1 of ammoniacal gas, to form muriate of ammonia: 2 volumes of oxygen combine with either 1 volume or 4 volumes of chlorine. The compounds of azote and oxygen fall under Gay-Lussac's general law, in the following manner:—1 volume of oxygen, and 2 volumes of azote, form protoxide of azote; 1 volume of azote, and 1 volume of oxygen, form deutoxide; 1 volume of oxygen, and 4 volumes of deutoxide of azote, form hyponitrous acid; 1 volume of azote, and 2 of oxygen, form nitrous acid; and 1 volume of protoxide of azote, were it to combine directly with oxygen to produce nitric acid, would require 2 volumes. Dr. Thomson, in referring to this law, as developed in Gay-Lussac's memoir, says, "In this paper, Gay-Lussac shows that the gases, considered in respect of their volumes, unite with each other in a very simple manner:—1 volume of one gas combining with 1 volume, with 2 volumes, or with *half* a volume, of the other."* I conceive that Dr. Thomson's enunciation of the law is more conveniently applicable to the facts than Gay-Lussac's, as in the case of the combinations of azote and oxygen. This most important law, which corrects analysis and synthesis, has been extended also to vapours; and even to the supposed vapours of bodies, which no degree of heat has been hitherto able to convert into the vaporific form; although it is certain that, combined with other matter, they are capable of existing in the state of ultimate division. Thus, 2 volumes of carbon vapour combine with 1, or 2, or 4 volumes of hydrogen, to form different varieties of carburetted hydrogen; and the same quantity of carbon vapour combines with 1 volume of oxygen, to form carbonic oxide; and with 2 volumes, to form carbonic acid.

It may be here necessary to explain more distinctly, what is to be understood by the term *carbon vapour;*

* First Principles, i. 18.

carbon being a substance which has never yet been obtained insulated in the vaporific form. If pure carbon be burnt in 100 cubic inches of oxygen gas, until the latter be saturated, the oxygen will be converted into carbonic acid, and the resulting volume will still be 100 cubic inches. The original weight of the oxygen was 33·9153 grains: the weight of the resulting carbonic acid is 46·5973: the weight acquired by the oxygen in forming carbonic acid is, therefore, 12·682 grains, which must consist of pure carbon. Now, it is obvious that this carbon had been divided into its ultimate atoms: it became invisible; and was, therefore, converted into a gas, which filled the space of 100 cubic inches in every part. The circumstance, that each atom of carbon is in combination with an atom of oxygen, does not in the least affect these statements: thus, carbon may be said, with sufficient truth for all theoretical purposes, to have been converted into vapour, of which 100 cubical inches weigh 12·682 grains; and of which the specific gravity is, therefore, 0·4116; and as there is neither condensation nor expansion in the formation of carbonic acid by burning carbon in oxygen, the condition of the carbon in carbonic acid is to be understood as meant, in chemical books, when carbon vapour is spoken of. But if carbon vapour were capable of existing in the insulated state, 1 volume of it would combine with 1 volume of oxygen, to form carbonic acid, and the 2 volumes would condense into 1.

In all the instances which have been adduced, the bodies concerned are subject to the law of multiple ratios, whether taken by weight or by volume. There is nothing mysterious in this coincidence of weights and volumes in the second, third, fourth, or fifth doses of any gas, A, which unites to another, B; they being only multiples by weight, and therefore by volume, of the first dose of A, as also of the volume of B. Thus, in the before mentioned compounds of azote and oxygen, we find, that to form protoxide of azote, 60·071 grains of azote combine with 33·915 grains of oxygen. It so

happens that these quantities saturate each other so far as the first stage of combination is concerned. There is nothing surprising in the fact, that 60·071 grains should be the weight of exactly 200 cubic inches of azote; for that number of grains has been here assumed, merely because it is the weight of 200 cubic inches: any other number of inches or grains would do as well, except for the arithmetical convenience. But it is a very remarkable fact, that 33·915 grains of oxygen — namely, the quantity required to saturate the 200 cubic inches of azote — should be the weight of 100 cubic inches of oxygen, or exactly *half* the volume of the azote; for here could be no assumption of any certain number of grains to answer a purpose — the weight, and therefore the volume, being determined by the affinity.

This has been generally considered an ultimate fact, — a truth of which no explanation can be given. But it is so obviously and immediately connected with the atomic constitution of matter, which has been of late years so fully developed, that the solution of it cannot much longer remain unattained. Indeed, some ingenious speculations as to the cause of it have long since been advanced, but they appear to be inapplicable. I have often thought that an explanation of this obscure part of the atomic hypothesis may be derived from another part, which has been generally admitted. To explain my views, several considerations must first be adverted to.

Two opinions have divided philosophers relative to the nature of caloric: according to some, it is matter; according to others, it is motion of matter. Those who deny its materiality, rely much on the fact, that it seems destitute of gravity — the common attribute of all known matter. The argument does not strike me with much force. It is certain, that the nicest balance does not discover any *real* difference between a cold body, and the same body heated. Weighing proves, perhaps nothing in this case. Hydrogen is certainly matter, and in large quantity is easily shown to possess weight: but in practice it is found a difficulty to weigh so large

a volume as even a cubic inch of it: the balance becomes overloaded, and its sensibility overpowered by the weight of the containing apparatus, and its counterpoise. The same happens when heated bodies are weighed: there must be containing matter for the caloric; and the quantity of this matter must be considerable, to contain a sufficient quantity of the caloric. When we consider that the statical experiments alluded to, were not made in a vacuum, but in the air, it is plain, that even if the caloric really possessed a little weight, it might not be discoverable. Most people conceive electricity to be matter: it can be made to perforate a quire of paper; it will strike into the earth, and make a deep hole; it will split trees, and throw down the most massive buildings. It is difficult to understand how these effects can be brought about, unless by a material agent: yet who doubts that electricity is destitute of weight? On the subject of matter — what it is, and what it is not, there is little use in speculation. We know that some eminent geniuses have even come to the conclusion that matter is nothing, — that it does not exist. Such a conclusion, if relied on, would render the explanation of all physical phenomena exceedingly embarrassing. Taking the word, then, in its usual acceptation, I shall, in the following observations, assume caloric to be matter.

If caloric be matter, it is probable that it resembles all other bodies, in possessing and being subject to that species of attraction called affinity. This opinion was maintained by Black, Pictet, Irvine, De Luc, Crawford, Lavoisier, La Place, and Thomson. Lavoisier says, that caloric is fixed in bodies by affinity, so as to form part of the substance, or even of the solidity, of the body. Dr. Black speaks in very remarkable terms: — he says, "A particle of water *attracts* and *unites* with *one or more atoms of heat*; these atoms of heat are *set at liberty by the fixed laws of chemical affinity*." — (*Lectures*, i. 165.)

This affinity has even been made the subject of cal-

culation by Avogadro *; and he has constructed a table, in which the relative affinity of various substances for caloric is expressed numerically,—the affinity of common air for heat being taken as unity. These numbers he deduced from the specific heat of gases, as given by Berard and Delaroche.

We discover caloric entering into a state that seems to possess the characteristics of chemical combination; for a decided change of properties is manifested. Caloric, when presented to ice, is absorbed; the ice loses most of its properties as such, and becomes water, while the caloric loses its chief remarkable property of raising the temperature. The same observations apply to all other cases in which heat becomes latent; and other illustrations of the position derived from specific heats might be adduced did space permit.

If there exist a reciprocal attraction between caloric and all other kinds of matter, why may not such an attraction be subject to the general laws of affinity? Why may we not suppose that the exertion of such affinity causes bodies to combine with caloric, atom to atom, and thus produces combinations bearing a determinate ratio to each other? We are not in the habit of considering determinate ratios of heat, or atoms of it; yet such may exist: and if experience prove that such an admission harmonises with, and leads to, the explanation of phenomena, which otherwise must stand in the situation of ultimate facts, then we are bound to admit the notion as probable. It is no more than an hypothesis; but hypotheses are often the beacons of discovery: the atomic constitution of matter was an hypothesis in the hands of Higgins; yet what department of the science has not since experienced its beneficial influence?

There are some combinations of carbon with hydrogen which may be here referred to, as illustrative of this part of the subject: they are gases; and have been described at page 170. of this volume. The first con-

* Giornale di Fisica, dec. ii. tomo viii. p. 1.

sists of 2 volumes of carbon vapour, and 2 volumes of hydrogen, both condensed into 1 volume; the second consists of 3 volumes of each, condensed into 1; and the third of 4 volumes of each, condensed into 1. Here, then, are three different gases containing the same ingredients, in the same ratio, but in different quantities: we have 4, 6, and 8 volumes respectively, condensed into 1, but so far differing in their state from what would be the result of mechanical condensation, that they spontaneously retain the equality of their respective volumes. It is probable that in each of these gases, the compound particles consisting of carbon and hydrogen are at, and are maintained at, different and determinate distances from each other. Now the particles are at distances from each other, because they are kept so by interposed caloric; and they are at *determinate* distances from each other, most probably because the quantities of caloric are determinate with which the compound particles of carbon and hydrogen are combined. If, from that gas which consists of 4 volumes condensed into 1, we could remove one dose of caloric, we should probably reduce it to the state of the gas which contains 6 volumes in 1; and were two doses removed, the resulting gas would, perhaps, be reduced to the state of the compound which contains 8 volumes in 1. In the same manner, were it possible to remove a determinate quantity of caloric from any gas, without further alteration in constitution, the result would, no doubt, be a permanent contraction to a volume which would bear some simple ratio to the original bulk.

We have now to apply this hypothesis to the phenomenon proposed to be explained. The phenomenon itself may be briefly recapitulated as follows: — When bodies not gaseous, C and D, combine in definite ratios by weight, although the second, third, fourth, &c. doses of D are all multiples of the first dose of D, the first dose of D is not a multiple or submultiple of the quantity of C which enters into the combination. But when two gases, A and B, combine, even the first dose of B

bears a simple ratio to A, being either equal, or double, or triple, &c., provided that volumes are considered; but if the quantities are estimated by weight, this peculiarity of the first dose disappears, and the law of multiple ratio is only observable in succeeding doses.

To account for a coincidence of volumes so unexpected, it was supposed, first by Avogadro, and afterwards by Ampere, that in all gases, simple or compound, the temperature and pressure being alike, the ultimate particles or atoms are at equal distances; and that the number is the same in equal volumes of all gases, or, in other words, is in proportion to the volume.* According to this view, the specific gravity of the gases would depend on the specific gravity of the atoms: other views might also be taken. Admitting this to be the constitution of gases, the explanation of the singular ratio observed as regulating the first dose of B to A becomes easily intelligible. If 100 cubic inches of oxygen combine with 100 cubic inches of azote, to form one compound; and with 200 of azote, to form another, it is plain that, as, according to the hypothesis, the number of ultimate particles or atoms is equal in equal volumes of all gases, each particle of oxygen must have combined with a particle of azote in the first instance, and with two of azote in the second. In short, granting the hypothesis, the phenomena naturally and consistently flow from it; and the apparently mysterious relation of the volume of the first dose of B to the volume of A, is in no way surprising; as the number of atoms is the same in each, and they unite atom to atom. It appears to me, however, that the hypothesis is untenable on many accounts. We can no longer suppose that the number of atoms is the same in all gases, for we have instances of the contrary — at least, according to the evidence afforded by the analyses which have been made. The three varieties of carburetted hydrogen which contains respectively —

* Giornale di Fisica, dec. ii. tomo viii. 1. Annales de Chimie, tome xc. 43.

	Gaseous carbon.		Hydrogen	
Variety	1st, 2 vols.	combined with	2 vols.	condensed
—	2d, 3 vols.	- -	3 vols.	into 1
—	3d, 4 vols.	- -	4 vols.	volume,

as explained in page 170., show that the number of atoms in these three gases cannot be the same. From this exception we may be led to suspect that there are others, and to conclude that the hypothesis is incompatible with the present state of knowledge.

The opinion relative to the constitution of gases with regard to determinate ratios of caloric, which has been above suggested, seems to harmonise tolerably well with the phenomena. If caloric be matter, it may be the subject of chemical attraction; if it be chemically attracted, it may combine in determinate ratios; if it combine in determinate ratios, the gaseous compounds formed must exist in determinate volumes. According to this view, the abstraction of a dose of caloric from a gas, in which it had been chemically combined, would cause it permanently to contract to a half, or a third, or any aliquot part of its original bulk; and the addition of a dose of caloric would, when combined, cause it permanently to dilate to double, triple, or any multiple of its first volume. In short, if caloric combine chemically with the atoms of different kinds of matter in determinate ratios, so as to form different gases, it would follow that, adopting as unity that gas which contains the fewest atoms, the number of atoms in all other gases would be multiples of the first by an integer.

Were gases thus constituted, they should always unite in the ratio, not only of weight, but of volume, that is observable in such cases; and such a constitution would assign a sufficient reason for the relation of volume which subsists between two gases when they enter into the first stage of combination; — a relation which the hypothesis, that all gases of the same volume, temperature, and pressure, contain the same number of par-

ticles, seemed to account for, but which appears no longer tenable.

That, under the same pressure and temperature, equal volumes of all gases contain an equal number of particles, is opposed to the opinions of those who understand the atomic hypothesis, as it flows from the general rule laid down by Mr. Dalton as a guide in investigations concerning chemical synthesis, viz. that "when two combinations are observed, they must be presumed to be a binary and a ternary." There are two combinations of oxygen and hydrogen: water must, therefore, be binary; that is, in two volumes of hydrogen there must be as many atoms as there are in one volume of oxygen, which is irreconcileable to the hypothesis of Avogadro and Ampere, although consistent with the views of Berzelius and Davy.

The hypothesis of equal volumes of all gases containing an equal number of atoms, fails also in another way; it assigns no reason for the remarkable contraction in a simple ratio to the original volume, which several gaseous compounds undergo at the moment of their formation. It is necessary first to state the law, and to give a number of instances of this contraction; the objection may be then applied. Gay-Lussac, the discoverer of the fact, says, "Not only do gases combine in very simple proportions, but the apparent contraction of volume which they suffer by combination bears, also, a simple relation with the volume of the gases, or, rather, with that of one of them."

When 1 volume of oxygen, and 1 of azote, combine to form deutoxide of azote, the result is 2 volumes, as computation would indicate; hence, there is no condensation. But when 1 volume of oxygen, and 2 of azote, unite to form protoxide of azote, the resulting bulk is not 3 volumes, but 2; hence there is one third of the whole bulk lost by approximation of the constituent atoms. When 1 volume of azote and 3 of hydrogen unite, the ammoniacal gas formed does not amount to 4 volumes, but 2; half is therefore

lost by condensation: 2 volumes of oxygen, and 4 of chlorine, do not afford 6 of protoxide of chlorine, but 5.

We have, in short, reductions from 2 volumes to 1, 3 to 1, 4 to 1, 8 to 1, and 9 to 1; and from 3 to 2, 5 to 2, 7 to 2; and one of 6 to 5. It is observable, that all the volumes concerned, both combining and resulting, are whole numbers; fractional quantities never occurring in well ascertained cases. These contractions only show that, during combination, the particles of the gases do not remain at the same distances, but approach each other so as to present a resulting volume of the compound gas which bears the above mentioned simple ratio to the sum of the two component gases. We may, therefore, express the law generally, by declaring, that when contraction does take place, it is so related, that the same unit measures the volume that disappears, the volume of each of the gases which combine, and the volume of the resulting compound gas.

In explanation of this rate of contraction, it might be supposed that either of the combining gases surrenders its caloric, and merges its volume; and such an explanation might apply, if the resulting volume always corresponded with either of the combining volumes. But this is only sometimes the case: ammoniacal gas, for instance, is formed from 1 volume of azote, and 3 volumes of hydrogen; the resulting bulk is 2 volumes; which would not be the case, had either the azote or hydrogen surrendered its gaseous existence. When the atoms of azote and hydrogen combine, the atoms of ammonia formed, retain the quantity of heat proper to themselves: but the singular fact, that the quantity of heat retained is just sufficient to enable the newly formed gas to occupy a volume, bearing the ratio to the original gases already stated, remains unexplained, unless the existence of definite ratios of combined heat be admitted.

I have not been deterred from advancing these notions, vague as they at present are, on account of any

considerations derived from the specific heats of gases, suspecting that we have as yet no certain knowledge of that subject: it is not even agreed whether they are the same in all, or different for each: and when we find the experiments of Delaroche and Berard diametrically conflicting with those of Marcet and Delarive, it seems but prudent to abstain from coming to any conclusion on the subject.

There is a consideration relative to Gay-Lussac's discovery of the law of volumes, which seems not to have been attended to by chemists. The law has been conceived to consist of two distinct positions: first, that gases combine 1 volume with 1 volume, or 1 with 2, or 1 with 3; second, that when contraction follows combination, the resulting volume "bears also a simple relation with the volume of the gases, or rather with that of one of them," as it is expressed by Gay-Lussac. Does not the second position flow from the first? and do not both indicate parts of the same phenomenon? Two volumes of muriatic acid gas saturate 2 volumes of gaseous ammonia; and 2 volumes of ammonia consist of 3 volumes of hydrogen, and 1 volume of azote. If the 3 volumes of hydrogen and 1 of azote did not condense into exactly 2 volumes of ammonia, but occupied the bulk of suppose $2\frac{1}{7}$ volumes, then the first position of the law could not be fulfilled in the combination of $2\frac{1}{7}$ volumes of ammonia with 2 of muriatic acid gas. The same kind of observation applies to the 2 volumes of muriatic acid gas composed of 1 volume of hydrogen combined with 1 of chlorine. Again, if oxygen, in being converted into carbonic acid, suffered the slightest expansion or contraction, the law of volumes could not be obeyed in the saturation of 1 volume of carbonic acid by 2 of ammonia. Were any expansion or contraction to take place in the generation of carbonic acid, it should be at least in such a ratio as would permit a multiple combination with all other gases.

In the foregoing pages of this chapter, it has been shown, as fully as the small space which can be allotted

to the subject would permit, that matter combines chemically with matter in limited quantities; that within the limit there frequently are determinate and successive stages of combination, in each of which the ponderable quantities giving origin to the successive stages are equal; that this equality of ponderable quantities is observable in solids and in gases; and that, in the case of gases, it is observable as well when the quantities are determined by volume. It now only remains to ascertain the amount or value of the combining quantities.

Affinity is a property of all matter. it acts in such a manner between two bodies, that, when they combine, they do so in quantities which are constant for the same bodies; and this is the case, whether there is one combination or more. Forty parts of sulphuric acid saturate 32 parts of soda; and the same quantity of acid saturates 28 of lime. These quantities of soda and lime are then so far related, that each is the representative of the other, with regard to the power of saturating 40 parts of sulphuric acid. The question occurs, is the acidity of sulphuric acid such that the ratio of the alkaline bodies to each other exists with regard to saturating *it only*? or, is acidity a general property, the same in all acids, so far as the ratio of the alkaline bodies adequate to saturate it is concerned? The latter form of the question must be answered in the affirmative. We find that the above mentioned quantities of the two alkaline bodies agree in the property of being saturated by 54 of nitric acid. Thus, a remarkable relation subsists between these quantities of the four substances concerned: 40 parts of sulphuric acid act the same part as 54 of nitric acid, in saturating 32 parts of soda, or 28 of lime: they are all *equivalents* (as they are now pretty generally called) to each other in saturating power: they are the *combining weights* of these substances: they are the *representative numbers,* from which we learn the ratio of the quantities that saturate each other. We learn from this ratio, that if 72 parts (40+32) of sulphate of soda, and 82 parts (54+28)

of nitrate of lime were mixed, the known order of affinities would prevail, and a total decomposition would ensue: the 40 parts of sulphuric acid, which had been saturated by 32 of soda, would now be equally saturated by 28 of lime; that is, the equivalent of 32 of soda; and 68 parts of sulphate of lime, would be formed: and the 32 parts of soda, now liberated, must be saturated by 54 of nitric acid; the latter being the equivalent of 40 parts of sulphuric acid, which had formerly saturated the soda. Thus, the result of the decomposition would be 68 parts of sulphate of lime, and 86 parts of nitrate of soda; and there would be neither free alkali nor free acid to be found in the mixture.

Indeed, in all such double decompositions, if the original salts were neutral, so will the resulting salts, unless in a few cases of complicated affinity which need not here be specified: and it cannot be otherwise. For if a salt, consisting of an acid, A, and an alkali, B, be neutral, it is so because A saturates B: if, then, that salt be decomposed by another, consisting of an acid, C, and an earth, D, the acid C being just sufficient to saturate B, which had been previously saturated exactly by A, then A and C are equivalents; and it is nothing surprising that A should saturate D, which had been previously saturated by C. Neutrality must result: the two salts may, perhaps, not totally decompose each other; but the result of any decomposition that does take place will be neutrality.

We may extend the number of the four equivalents above mentioned, throughout the whole catalogue of the different bodies in nature. Whatever quantity of potash saturates 40 of sulphuric acid, will be the equivalent of 32 parts of soda, and of 28 of lime; and will be saturated as well by 54 of nitric acid: this quantity of potash is 48 parts. Whatever quantity of carbonic acid saturates 48 of potash, or 32 of soda, or 28 of lime, will equal the saturating power of 40 parts of sulphuric acid, or 54 of nitric acid: this quantity of carbonic acid is 22 parts. Or, it will be found, that 42

parts of oxide of zinc will saturate 40 parts of sulphuric acid, and, consequently, 54 of nitric acid, and 22 of carbonic; and to these, or any other acids, it will be equivalent in saturating power to 32 of soda, 28 of lime and 48 of potash. These observations have presented us with the following scale of equivalents, the names representing the bodies to be combined, and the numbers showing the quantities in grains, pounds, or tons, or any other denominations, which saturate each other, in such cases as combinations actually take place:— Sulphuric acid 40: nitric acid 54: carbonic acid 22: oxide of zinc 42: potash 48: soda 32: lime 28.

Now, as all these bodies are compound, and are equivalents to each other, it would follow, as a consequence, that the elements of which they are composed are also equivalents to each other in relative quantity; and that, in the case of any two of these bodies—sulphate of zinc, for instance—we are not merely to consider that salt as composed of sulphuric acid and oxide of zinc, in a certain ratio to each other, but as composed of sulphuric acid, zinc, and oxygen. The 42 parts of oxide of zinc consist of 34 parts of zinc and 8 of oxygen: consequently, 34 is the equivalent number for zinc, and 8 for oxygen. If we examine potash, soda, and lime, in the same manner, we should, of course, find 8 constantly the equivalent for oxygen: thus, 48 parts (the equivalent) of potash consist of 40 parts of potassium and 8 of oxygen: 32 parts (the equivalent) of soda consist of 24 sodium and 8 oxygen: and 28 parts (the equivalent) of lime consist of 20 calcium and 8 oxygen. Thus we have obtained the following additional equivalents:— Oxygen 8; zinc 34; potassium 40; sodium 24; calcium 20.

But the acids above enumerated are also compounds: they consist of oxygen and a base; it is, therefore, necessary to discover if the oxygen is the same in them as in the substances just examined. Sulphuric acid, in 40 parts (its equivalent), contains 16 of sulphur, and so much as 24 parts of oxygen: nitric acid, in 54 parts

(its equivalent), contains 14 of azote, and 40 parts of oxygen: and carbonic acid, in 22 parts (its equivalent), contains 6 of carbon and 16 of oxygen. In these acids, we, therefore, have the oxygen as 24, 40, and 16; and in the former estimate we have it 8. But as 8 is the quantity which exists in oxide of zinc, potash, soda, and lime; and as 24 is three times 8, and as 40 is five times 8, and 16 is twice 8, it is evident that 8 is the real equivalent number; that in sulphuric acid there are 3 doses of oxygen, in nitric acid 5, and in carbonic acid 2. These analyses afford the following additions to the list of equivalents, the numbers being found by subtracting the oxygen in each case: sulphur 16; azote; carbon 6.

In water the oxygen is 8 parts, the hydrogen 1 part, both by weight: 8 being the equivalent of oxygen, 1 is the equivalent of hydrogen. The following table presents all these bodies, with their respective numbers:—

Hydrogen	1	Lime	28
Carbon	6	Soda	32
Oxygen	8	Zinc	34
Azote	14	Sulphuric acid	40
Sulphur	16	Potassium	40
Calcium	20	Oxide of zinc	42
Carbonic acid	22	Potash	48
Sodium	24	Nitric acid	54

And we may easily find the equivalents of any of the compounds of them by adding the numbers together: thus water will be $8+1=9$; nitrate of lime will be $54+28=82$, &c. The value and meaning of this table will be more fully seen in the following observations:—

The numbers representing the equivalents in the table, may be increased or diminished to any extent: hydrogen, instead of being 1, may be represented by the number 100, or by 1000, or 999, or any other number, provided that all the other numbers are multiplied in an equal ratio. Or hydrogen may be represented by

$\frac{1}{1000}$ or $\frac{1}{10000}$, if all the other numbers are equally diminished. If hydrogen were 100, oxygen would be 800, nitric acid 5400. Were hydrogen 0·01, oxygen would be 0·08, and nitric acid 0·54;—numbers all equally inconvenient either to write or to speak. It is the ratio that renders them of value: the table informs us, that 40 parts of sulphuric acid would saturate 48 of potash; but there is nothing useful in the numbers 40 and 48 more than in 20 and 24, or 5 and 6: it is the ratio of the sulphuric acid to the potash which we require to know, and of which we are informed by the table. Every one knows that the larger the numbers in any series are, the more difficult it becomes to perceive their relation. Thus the relation of the numbers in the progression 1, 2, 3, 4, 5, &c. is obvious on inspection; but it would not be so were we to express the same relation by the numbers 129, 258, 387, 516, 645, &c. Hence, it has been an object to reduce the equivalent numbers to the lowest ratio that can be obtained.

But, the ratio being the main object of the scale of equivalents, it may be enquired, why are not the numbers reduced far below what are given above? for the scale, if extended so as to include all known bodies, will give numbers higher than 500. To understand the answer to this question, we must first consider the nature and constitution of numbers in general, so far as is necessary to a clear comprehension of the nature and constitution of the numbers which represent chemical equivalents.

Euclid defines number to be a multitude of *units*. Mr. Locke observes, "Amongst all the ideas we have, as there is none suggested to the mind by more ways, so there is none more simple, than that of *unity* or 1. It has no shadow of variety or *composition* in it: every object our senses are employed about, every idea in our understandings, every thought of our minds, brings this idea along with it." — "By repeating this idea (unity) in our minds, and adding the repetitions together, we have the complex idea of a million, or any other

number." Euler defines number to be "the proportion of one magnitude to another *arbitrarily assumed* as the unit." In short, we can have no idea of any number, but in reference to some standard which measures that number; and that standard is 1, or unity. In its own nature unity is not a number, and, therefore, it is indivisible: for, even though it should really consist of parts, "it has no shadow of composition in it," and it is "arbitrarily assumed" to be *one*. Such is the nature of the unit of number; and this nature will now be shown to correspond with the unit of the table in question.

On inspecting the table of equivalents, we learn that, to form potash, 40 parts of potassium must combine with 8 of oxygen. The table gives the quantity, but not the quality, of the relative weights: it does not declare whether the weights are grains, ounces, or pounds. In practice, it may be any of them; in general, it may be *parts*; but, in the theory and construction of the table, a very different denomination, from any palpable weight, is implied. When we consider the numbers concerned, viz. 40 and 8, they convey no idea, unless they refer to the unit, or measure, of all the rest: forty times *something else*, and eight times the same, are both implied by the numbers. The *measure* expressed in the table is hydrogen; it is called 1, and is therefore the unit. This affords the reason why the numbers in the table are so high: they all refer to hydrogen as unity; and hydrogen enters into combination in very small quantities, partly owing to its lightness compared with its bulk, and partly to its great saturating power. For instance, the weight of hydrogen that combines to form ammonia, is almost five times less than that of the azote: the weight of hydrogen, in sulphuretted hydrogen, is only $\frac{1}{16}$th; and, in hydriodic acid, it is but $\frac{1}{124}$th. It is obvious, that the less the weight of hydrogen is, which combines with other bodies, the greater must be the weight of those bodies which

combine with it: for the terms *more* and *less* are correlatives.

The necessity of an unit having been thus pointed out, the next enquiry is, concerning the denomination of which this particular unit is, as it is not the measure of any palpable weight known in practice. The most intelligible mode of introducing the subject, will be to detail the circumstances which led to the idea of employing equivalent numbers. Mr. Dalton was the first who distinctly conceived that, from the relative weights of the elements in the mass of any compound body, the relative weights of the ultimate particles or atoms of the bodies may be inferred: and that, from this, their number and weight, in various other compounds, would appear in such a way as to assist and guide future investigations, and to correct the results. He inferred the relative weights of the atoms in the following manner:—Water, he conceived to consist of 1 part, by weight, of hydrogen, and 7 of oxygen. It must be presumed, he thinks that, when two combinations of two bodies can be obtained, the first must be composed of an atom of each combined; and the second, of 2 atoms of one, and 1 atom of the other." Applying this rule to the two combinations of oxygen and hydrogen, we must suppose that water consists of an atom of hydrogen combined with an atom of oxygen: and, if this be admitted, the weights of the atoms must be in the same ratio as the weights of the total quantities that compose water. Hence, an atom of hydrogen will weigh 1, and the atom of oxygen will weigh 7. Ammonia, Mr. Dalton conceived, to consist of 1 part of hydrogen, combined with nearly 5 of azote; and, as he considered ammonia as composed of an atom of each element, there being but one known combination of hydrogen and azote, the weight of the atom of hydrogen is 1 as before, and that of the atom of azote is about 5. Carbonic oxide, consisting of oxygen and carbon in nearly the ratio of 7 to 5, and being composed of an atom of each element, the atom of oxygen will weigh 7 as before, and the atom of carbon

about 5: and the weight of an atom of carbonic oxide will be 7 + 5 = 12.*

In this way he proceeded to examine many compounds, first assuming the weight of an atom of hydrogen to be unity, and, from that, determining the weight of the atoms of other elements, by representing them as so many times heavier than the atom of hydrogen — the number of times being discovered by comparison of the weights of the different elements. These weights were determined by analysis of the compound formed either with one part of hydrogen, or with a given weight of some other element, the relation of the atomic weight of which to that of hydrogen had been already ascertained. Thus, the weight of the atoms of other bodies were expressed in atoms of hydrogen, each of which was denoted by unity.

The reason for adopting hydrogen as unity, is, because that body, of all others, enters into combination in the smallest weight: hence Mr. Dalton considered hydrogen to be the most proper unit. We now see that this unit is an atom; and that an atom corresponds with the simple and indivisible nature of an unit: for an atom, without a contradiction in terms, can have no parts.

It will be useful to reconsider a few of the equivalents in the table already given, and to show in what manner these numbers have been derived, so different as they are from the numbers originally given by Dalton. Water is now known to be a compound of 1 part of hydrogen and 8 of oxygen, both by weight. It is conceived that, in water, the two gases are combined, atom to atom; which is the same as to say, that there are as many atoms in 1 part, by weight, of hydrogen, as in 8 of oxygen: and, if this be so, it is quite clear, that, assuming the atom of hydrogen as 1, for the reasons already assigned, the atom of oxygen must be 8 times heavier. Hence, in the table, hydrogen is called 1, and oxygen 8. But no assertion is made further than regards the ratio of their weights: nothing is conveyed as to the

* All these atomic weights, given by Mr. Dalton, have been altered in consequence of subsequent investigations.

actual number of particles of either oxygen or hydrogen contained in a given weight of these gases.

Again: olefiant gas is composed of equal volumes of hydrogen and carbon vapour. 100 cubic inches of carbon vapour weigh 12·682 grains, and the same volume of hydrogen, 2·1197; that is, a volume of carbon vapour weighs 6 times (*qu. pr.*) more than an equal volume of hydrogen. If it be assumed, that these two gases unite atom to atom, it is quite clear that, without asserting any thing as to the number of the atoms in any volume of these gases, we may conclude, the atom of carbon is 6 times heavier than that of hydrogen: hence, the latter being 1, the former is rated 6 in the table.

The same atomic weight may be derived in another way. Carbonic oxide consists of 33·9153 parts of oxygen, and 25·364 of carbon, both by weight: that is, the weight of the oxygen is to that of the carbon, as 1·3371 to 1. Now, as it is assumed that the oxygen and carbon combine atom to atom, it is plain, that the atom of the former will be to the atom of the latter, in weight, as 1·3371 to 1. But the atom of oxygen has already been shown to weigh 8: therefore, as 1·3371 is to 1, so will 8 be to 6 (*qu. pr.*); and thus again we obtain 6 as the atomic weight of carbon. Here it is to be observed, that the atomic weight of carbon has been obtained, *apparently*, without reference to that of hydrogen. But it has been compared with the atom of oxygen, and that was originally obtained by comparison with the atom of hydrogen. The atomic weight of carbon is, therefore, indirectly derived from a comparison with that of hydrogen.

We may also infer the atomic weight of carbon from marsh gas and carbonic acid, with instructive results. Marsh gas consists of carbon 12·682 parts, and hydrogen 4·239, the ratio being very nearly as 3 to 1. When these quantities unite, it cannot be supposed that they combine atom to atom; for that was the supposition in the formation of olefiant gas. The hydrogen

is now double the weight; hence its atoms are double the number: and as the weight of the carbon is to that of the hydrogen, in the case of marsh gas, as 3 to 1, and as in the 1 of hydrogen there must be two atoms, the real weight of carbon is as 6 to 1; that is, the atomic weight of carbon is again found to be 6.

Carbonic acid consists of 33·9153 parts of oxygen and 12·682 of carbon; the former is to the latter as 2·674 to 1. But the volume of oxygen in carbonic acid is twice as great as it is in carbonic oxide; so also must be the number of atoms. Hence, the ratio of weights being as 2·674 to 1, and the former number representing 2 atoms of oxygen, we have the proportion 2·674 : 1 : : 16 : 6 (*qu. pr.*).

The atom of azote is deduced from the composition of protoxide of azote. To form this, 33·9153 parts of oxygen combine with 60·071 parts of azote; hence the azote is to the oxygen as 1·771 to 1: and as the atomic weight of oxygen has been already proved to be 8, and the two elements combine atom to atom, we have 1 : 1·771 : : 8 : 14 (*qu. pr.*). Hence the atomic weight of azote is 14.

The weight of the atom of sulphur may be derived from sulphuretted hydrogen, which consists of 2·1197 parts by weight of hydrogen, and 34·2 of sulphur. The weight of the sulphur is, therefore, to that of the hydrogen, almost exactly as 16 to 1. Hydrogen being unity, the atomic weight of sulphur is 16.

From these examples it appears, that the atomic weights are all derived, directly or indirectly, from hydrogen assumed as unity: and as the unit in the table of equivalents is an atom, so also the equivalent numbers are multiplications of that atom. It is, therefore, manifest, that nothing is known of the real weight of an atom in any ponderable or practical denomination, such as grains, &c. An atom must certainly possess physical weight, be it ever so minute; but as it is totally inappreciable, we are utterly ignorant of it. It therefore follows, that the numbers in the table of equiva-

lents do not really represent ponderable quantities, although they may be used as such. They merely represent ratios of weights, and not the weights themselves. When it is said that the atom of carbon is 6, it is intended to affirm that its atom is six times heavier than the atom of hydrogen, assuming the latter arbitrarily as a standard of comparison, and not professing to understand the value of that standard. In the same manner, we say that the atom of oxygen is 8 times heavier than that of hydrogen; and hence (adding 8 to 6), that the atom of carbonic oxide is 14 times heavier than the atom of hydrogen.

But we must also view these numbers under another aspect. If they represent the comparative weights of atoms, and if bodies combine atom to atom, these numbers must, as already stated, represent the ratio in which bodies combine and saturate each other; hence the name *combining weight*, given to them by Dr. Young. Thus, if 16 represent an atom of sulphur, and 1 an atom of hydrogen; and if sulphur and hydrogen unite atom to atom, then 16 parts (whether grains or pounds) ought to saturate 1 part of hydrogen, and thus form 17 parts of sulphuretted hydrogen; and the number 17 should also be the atomic weight and combining quantity of that gas. This is true; for we find that 17 parts of sulphuretted hydrogen enter into combination with 56 of sulphuret of potassium. This last number is the atomic weight of sulphuret of potassium—it being composed of an atom of sulphur = 16, and an atom of potassium = 40. It is in this way that the table of equivalents becomes of such vast importance to the practical chemist, especially when laid down on a scale with a slider, as in Wollaston's scale of equivalents, which even performs arithmetical operations on compositions and decompositions.

On inspection of the table of equivalents above given, it will be found, that the numbers are all multiples of the weight of hydrogen, and that, of course, no fractional numbers occur. Indeed, the same observation applies

to the equivalent numbers of all the bodies known, with but very few exceptions. The singular circumstance, that the first adopted unit* should exactly measure the atoms of all the substances which were afterwards reduced under the law of multiple ratios, might be explained by supposing that the atom of hydrogen is the natural and real unit of all matter; or, more probably, that fractions have been removed by the corrections made in the analysis of bodies, according to a practice now almost invariably adopted and allowed by chemists. Notwithstanding this coincidence, it has been considered by the majority of good judges, that there are countervailing advantages in assuming oxygen as unity, in place of representing it by the number 8. If oxygen be considered 1, we must then reduce the whole scale of equivalent numbers to $\frac{1}{8}$th of what they would be were hydrogen 1. Thus, sulphuric acid, which in the table is 40, would then be 5; and nitric acid, instead of being 54, would be 6·75: lime, instead of 28 would be 3·5: carbonic acid, from 22, would change to 2·75; and hydrogen would be 0·125. In this case, almost one half of all the ascertained numbers would be fractional; but they are almost always those fractions which are easily remembered, such as $\frac{1}{4} = 0{\cdot}25$, or $\frac{1}{2} = 0{\cdot}5$, or $\frac{3}{4} = 0{\cdot}75$. Dr. Thomson, in advocating the oxygen scale, says, "Surely it will not be said that the fractional numbers are more unwieldy or unmanageable than the whole numbers; while, in all cases of whole numbers, the advantage on the side of the latter method is very great. Thus, if hydrogen be unity, the atom of uranium is 208; while, if oxygen be unity, it is only 26."—(*First Princ.* i. 17.) On the other hand, Dr. Ure observes, "It has been objected by some, to our assuming hydrogen as the unit, that the numbers representing the metals would become inconveniently large. But this could never be urged by any one acquainted with the theory of numbers. For in what respect is it more convenient to reckon barium 8·75 on

* Hydrogen was the unit chosen by Mr. Dalton.

the atomic scale," or $8 \cdot 75 \times 16 = 140$ on sir H. Davy's scale of experiment? Or is it any advantage to name, with Dr. Thomson, tin = 7·375, or to call it 118 on the plan of the English philosopher? If the combining ratios of all bodies be multiples of hydrogen, as is probable, why not take hydrogen as the unit." It appears to me that the oxygen scale of numbers, considered with regard to numerical convenience only, has little or no advantage over the hydrogen scale. In writing, speaking, or thinking, the three figures, 8·75, seem to have no advantage over the other three figures, 140; and there are many such instances. Dr. Thomson assigns, also, the following reason for preferring oxygen as unity:—"Hydrogen, so far as we know at present, combines with but few of the other simple bodies; while oxygen unites with them all, and often in various proportions. Consequently, very little advantage is gained by representing the atom of hydrogen by unity, but a very great one by representing the atom of oxygen by unity: for it reduces the greater number of arithmetical operations, respecting these bodies, to the addition of unity; and we see at once, by a glance of the eye, the number of atoms of oxygen which enter into combination with the various bodies." This argument seems to me unanswerable. In the appendix to Dr. Thomson's System of Chemistry, recently published, there is a list of 390 bodies, the atoms of which are represented by numbers composed in all of 1026 digits for the oxygen scale, and 800 for the hydrogen scale. Thus, on an average, the number of digits employed for each body, according to the two scales, is as 1·31 to 1; a trifling disadvantage, compared with the great utility of subtracting, adding, or remembering the dose of oxygen belonging to a body by means of unity, and many other important substances by numbers not very much greater.

Either of the scales will answer the purpose. In order to convert the hydrogen scale into the oxygen

scale, divide the former by 8. If the oxygen scale be multiplied by 8, the product will be the hydrogen scale.

It is now necessary to show, that the numbers themselves, considered abstractedly as representatives of the weights of atoms, and without reference to their capacity of expressing combining ratios, are hypothetical and useless; and that they may be, in reality, very different from what we suppose them. As there are but two units employed, oxygen and hydrogen; and as both of these are contained in water, the composition of which is agreed on by all chemists; the analysis of water may be considered as the basis of the atomic hypothesis. Water consists of 1 part of hydrogen and 8 of oxygen, both by weight; or, what is the same thing, 2 volumes of the former and 1 of the latter. It is *inferred*, that in the 2 volumes of hydrogen there are exactly the same number of ultimate particles, or atoms, as there are in 1 volume of oxygen. But there are no grounds for the inference, beyond a supposed probability. It originated with Mr. Dalton, and was expressed in the following words:—"When only one combination of two bodies can be obtained, *it must be presumed* to be a binary* one, unless some cause appear to the contrary: and when two combinations are observed, they must be presumed to be a binary and a ternary."† Water is, therefore, inferred to consist of an atom of hydrogen combined with an atom of oxygen. It is further inferred, that a given volume of hydrogen contains but half the number of atoms contained in the same volume of oxygen: and as the weight of oxygen in water is 8 times greater than that of hydrogen, the atom of oxygen is inferred to be 8 times heavier than that of hydrogen. The truth of the fact inferred, however, depends on the truth of the assumption, that the two gases unite atom to atom;—a position which may be either denied or admitted at pleasure, for it is perfectly gratuitous. It may be affirmed, as equally probable,

* Mr. Dalton explains a binary compound to mean an atom of each element in combination

† A ternary compound is 1 atom combined with 2 atoms.]

that a volume of hydrogen consists of the same number of atoms as a volume of oxygen. In this case, the weight of an atom of oxygen will be 16 times heavier than an atom of hydrogen; and then, if oxygen be assumed as 1, an atom of hydrogen will weigh 0·0625, instead of its double, 0·125; or, if hydrogen be = 1, the atom of oxygen will weigh 16, instead of 8, and all the numbers in the table of equivalents must be doubled. In short, as we know nothing of the number or weight of atoms constituting hydrogen or oxygen gas, all numbers produced by multiplication of the atom of either must be conjectural, and only valuable so far as they express ratios to an unit assumed at pleasure.

Another instance of the fallacy of the general rule, that when two compounds are known, one is to be presumed to be binary and the other ternary, may serve to set this matter in a proper point of view. If hydrogen be = 1, oxygen will be = 8. Analysis shows that about 8 parts of oxygen combine with 200 of mercury to form the protoxide, and 100 to form the peroxide. If we take 8 as one atom of oxygen, and if, according to the rule, as there are two combinations, the protoxide is binary, then the atom 8 will unite to an atom of mercury, which, consequently, will be represented by 200. The atom of mercury has been hitherto, accordingly, rated at 200 in hydrogen tables of equivalents, and at 25 in oxygen tables. But we may just as well suppose that the protoxide consists of an atom of oxygen combined with 2 atoms of mercury; and then the number representing mercury is reduced to one half, that is, 100 or 12·5. This view has been adopted by Dr. Thomson, in the last edition of his System of Chemistry, for reasons which he has there stated, and which, whenever they will be founded on an extensive induction, will be of the utmost value in determining the real atomic numbers. In his Introduction, p. xiii., speaking of the tables of atomic weights, he says, " It is not unlikely that some of these numbers may be twice as high as they ought to be." But, at p. ix., he sums up

the real condition of the atomic numbers in the following: — "In many cases it is not easy to fix upon the true atomic weight of a body. We can always infer that the weight of one body that enters into combination with another, either denotes the atomic weight of the body, or at least a multiple or submultiple of that weight; but in some cases it may be very difficult to determine which of the three."

These statements hold true, whether we take oxygen or hydrogen as unity; and whether we admit the existence of atoms, or not. It has been supposed by some, that the doctrine of determinate proportions is a mere expression of facts, and essentially different from the atomic hypothesis, which is founded on the assumption of the finite divisibility of matter; or, in other words, on the atomic constitution of bodies. It appears to me, that there is as much hypothesis in one doctrine as in the other. We say that an indivisible atom of hydrogen = 1, combines with an indivisible atom of oxygen = 8; and the latter combines with an indivisible atom of mercury = 200. Here, it may be said, are three gratuitous assumptions: first, that the combining quantities are atoms; secondly, that they are indivisible; and, thirdly, that the bodies combine atom to atom. But in the doctrine which professes to embody facts only, we can detect these same three assumptions tacitly involved. According to this mode of expressing the phenomena, a certain quantity of hydrogen — the least that enters into combination—is called unity, even although it consists of 2 volumes; this is the very same position, in another form, that has been considered objectionable in the atomic hypothesis of Dalton. The quantity of oxygen with which this unites, is the least that enters into combination; and the quantity of mercury with which this last unites, is also the least that enters into combination. Here, then, we have three bodies taken in the least quantity that enters into combination. How does this quantity differ from an atom rightly understood? An atom does not mean a quantity which

cannot be divided; but one which *never is known* to be divided; combining quantity means the same: hence, whatever objection applies to one, applies to the other. And, in general, the tables of equivalents profess to contain the smallest weights which enter into combination; such, also, are atoms. By the application of certain principles, Dr. Thomson has reduced the weight of an atom of mercury to one half: the same reasoning similarly affects its combining quantity. In fine, whatever applies to one doctrine, seems to apply to the other; and both appear to be different methods of expressing the same thing.

If the truth of the law which is affirmed to govern multiple combinations be admitted, and if the law be believed to depend on the union of bodies, atom to atom, it must be universal in its operation, and there can be no exception. To admit an exception, would be to admit the existence of parts of atoms, which the atomic hypothesis excludes; for, the combining ratios must always consist of 1, 2, 3, 4, &c. atoms to 1. But, in point of fact, we find ratios that appear to militate with this law. Thus, 3·5 of iron, in order to form the protoxide, combine with oxygen 1 atom. According to the law of multiple ratios, we should expect that the second stage of oxidation would require 2 atoms of oxygen; whereas experiment proves, that 1½ atom is the real quantity that enters into the peroxide. With a view of removing this anomaly, Dr. Thomson says, "I need hardly observe, that we can get rid of these half atoms with the greatest ease, by merely doubling the numbers representing the constituents of the compound. Thus, if an atom of iron weigh 3·5, and an atom of oxygen 1, and if we consider it as absurd to view *peroxide of iron* as a compound of 1 atom of iron and 1½ atom of oxygen, we have only to double 3·5 and 1·5, which are the two constituents of peroxide of iron. By so doing, we get 7 = 2 atoms of iron, and 3 = 3 atoms of oxygen; and the peroxide of iron will be a compound of 2 atoms iron and 3 atoms oxygen."

It does not appear to me that the anomaly is here more than apparently removed: the fraction has certainly disappeared from the numbers, but it seems still to exist secretly. In order to admit this explanation, I think we must also admit—what chemists will scarcely assent to—that 1 atom of iron cannot be brought to the state of peroxide, since 2 atoms require 3, and since the only possible division of 3 is into three separate whole atoms. Such cases as this—and there are but few—should not be considered as exceptions, but as facts, the circumstances of which are not yet fully understood. Should it, as it very probably will, be hereafter discovered that there is an oxide consisting of 3·5 iron + 2 oxygen, we may then suppose that the second oxide is a compound of an atom of each of the other two oxides.

INDEX.

A.

B.

C.

D.

E.

F.

THE END.

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